Buildings and Infrastructure Protection Series

High Performance Based Design for the Building Enclosure

A Resilience Application Project Report

BIPS 10/November 2011

Homeland Security
Science and Technology

Prepared by the National Institute of Building Sciences

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Executive Summary

This Technical Report describes a project performed by the National Institute of Building Sciences (Institute) in partnership with the U.S. Department of Homeland Security (DHS) to address High Performance Based Design for the Building Enclosure (HPBDE). The Institute convened an expert team to develop a method for analyzing multiple performance objectives early in the project planning process. This method allows building owners to optimize their investments in building security, along with safety, energy conservation, environmental footprint and durability, in addition to evaluating the resulting risk and resilience of a proposed project. The model of performance developed by the Project Team was integrated within an online software program specifically focused on establishing Owner Performance Requirements (OPR).The OPR Tool provides project planners with a previously unavailable resource for selecting and documenting performance goals for a project. This first-phase effort, limited to enclosure systems for new office buildings, lays the technical foundation and software framework for expanding the approach in later phases to address retrofit of enclosure systems, as well as moving on to cover the whole building and additional building types.

Foreword and Acknowledgments

Background

The Energy Independence and Security Act of 2007 (EISA-2007)[1] defines a high-performance building (HPB) as one that "integrates and optimizes on a life-cycle basis all major high-performance attributes, including energy conservation, environment, safety, security, durability, accessibility, cost-benefit, productivity, sustainability, functionality, and operational considerations." EISA-2007 also established an aggressive plan for achieving energy independence (e.g., zero-net-energy) in the nation's building stock by the year 2030.

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A high-performance building (HPB) integrates and optimizes on a life-cycle basis all major high-performance attributes, including energy conservation, environment, safety, security, durability, accessibility, cost-benefit, productivity, sustainability, functionality, and operational considerations.

The U.S. Department of Homeland Security (DHS), Science and Technology Directorate's Infrastructure and Disaster Management Division (IDD) entered into a partnership with the National Institute of Building Sciences (Institute) to develop an Owner Performance Requirements (OPR) Model that establishes high-performance operational, resilience and risk targets and identifies the parameters that allow project owners to identify

1 Review of the Department of Homeland Security's Approach to Risk Analysis, The National Research Council, The National Academies Press, 2010

The OPR Tool is designed to help building owners in the public or private sector that are evaluating the feasibility of a new construction project.

their goals for a project, including type, size and location, and then evaluate alternative scenarios.

The model is strictly performance-based and does not identify prescriptive solutions for building systems to achieve performance objectives, leaving this to the subsequent work of the design team. The model, through the interactive OPR Tool, is useful for preparing scenario analysis during the planning and conceptual design phases of a prospective project. The OPR Tool is designed to help building owners in the public or private sector that are evaluating the feasibility of a new construction project. The tool is intended to be used by financial analysts, designers or developers familiar with building technology and planning. Its use fits with the recommendations of the ASTM E06.55.09 S*tandard Practice for Building Enclosure Commissioning*, which was recently balloted and for which the OPR Tool is expected to be an adjunct component. The use of the OPR Tool in the planning process and its function are discussed in Chapter 4 of this Report. The logic used in the OPR Model and the methodology employed in its development are discussed in detail in Chapter 6 of the Report. The OPR Tool is available for public use at www.oprtool.org.

The OPR Model extends the high-performance building objectives to cover security performance for blast resistance, ballistic protection and chemical, biological and radiological (CBR) protection as key evaluated elements along with the other EISA attributes. It is important to note that the Act defines high performance as the "integration and optimization on a life-cycle basis of all major high-performance attributes." Attention to the linkages between attributes provides an opportunity to incorporate blast, ballistic and CBR protection technologies with the new and innovative building enclosure technologies being developed to address the aggressive agenda laid down by EISA 2007.

In order to support achieving the goals of EISA 2007 and meeting the mission of DHS IDD to improve the security of critical infrastructure, the model employs multi-attribute analysis and performance modeling that includes evaluating interactions between the attributes of building design. The need to accommodate such interactions while performing risk analysis has been recommended by the National Research Council to achieve accurate results.

The OPR Tool is available for public use at www.oprtool.org

The team of technical experts, assembled by the Institute for their knowledge of risk and resilience-based modeling, multivariable analysis, performance-based design and decision making, created the model and the information that populates it. They established four levels of performance for developing results: Current Practice (Baseline),Improved Performance (P+), Enhanced Performance (P++) and High Performance (HP). Chapter 5, which addresses Technical Analysis, discusses the performance levels in detail and the Attribute-Performance Summary Tables in Appendix A summarize the full range of performance results identified by the project.

The OPR Model extends the high-performance building objectives to cover security performance for blast resistance, ballistic protection and CBR.

The HPBDE project in this phase initially evaluates the building enclosure (also commonly identified as the building envelope) for one building type – commercial office buildings. This limitation to the enclosure posed some challenges since the building enclosure interacts with other building systems. While those interactions were investigated for this project, especially in the case of the structural and mechanical systems, every effort was taken to isolate the evaluation to only the enclosure. Goals for future phases of the project are to expand evaluation to the complete structural, mechanical and electrical services systems (the whole building), retrofit (an enclosure retrofit version has been developed and will be included in the phase I release of the OPR Tool. The process employed to develop it will be documented in a forthcoming supplement to this report) and additional building types.

Organization and Content

The information is arranged in sections in the following order:

- Chapter 1: Introduction
- Chapter 2: Project Approach
- Chapter 3: The Owner Performance Requirements(OPR) Process
- Chapter 4: The OPR Tool in the Planning and Design Process
- Chapter 5: Technical Analysis
- Chapter 6: OPR Model Algorithms and Decision-Making Methodologies
- Chapter 7: Validation and Verification of Results
- Chapter 8: Conclusions and Recommendations

Appendices

- Appendix A: Attribute Performance Summary Tables
- Appendix B: EnergyPlus Simulation Analysis
- Appendix C: Detailed Mechanical Analysis

Acknowledgements

The Department of Homeland Security (DHS) Science and Technology (S&T), Infrastructure Protection and Disaster Management Division (IDD) produced this publication in partnership with the National Institute of Building Sciences (Institute).This Report may be revised periodically. Comments and feedback to improve future editions are welcome. Please send comments and feedback to bips@dhs.gov..

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http://www.oprtool.org

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1

Introduction

This Technical Report documents the logic the National Institute of Building Sciences and the U.S. Department of Homeland Security (DHS), Science and Technology Directorate's Infrastructure and Disaster Management Division (IDD) employed in the making of the Owner Performance Requirements (OPR) Model and Tool, the logic developed to structure decision making, the technical information identified to establish performance levels, the function of the OPR Tool that makes it interactive and how the OPR process fits in the building planning and design process. The Report begins with general information about the OPR process and is followed by a discussion of the model, its components in general and how the process is implemented using the OPR Tool. Next is a review of the critical elements of each major component of the building enclosure evaluated to meet increasing levels of demands or threats and targeted performance. This is followed by an in-depth review of the logical model and decision-making tools as well as the algorithms that underlie its function. Recommendations and Conclusions specific to selected sections are located at the end of that section and Recommendations and Conclusions for the whole project appear at the end of the Report. .

The determination of levels of building performance used in the OPR process relies on the expert opinions of a small group of technical specialists who establish the basis for alternative analysis and comparison. These experts' predictions of performance and estimates of cost require verification and validation to be continually proven useful and improved. Chapter 7 identifies the processes for validation and verification employed in this phase of the project and anticipated for subsequent phases.

The Project Report concludes with Recommendations and Conclusion for the project, followed by Appendices applicable to the whole project.

2

Project Approach

To identify and analyze high-performance building attributes, participants in the High Performance Based Design for the Building Enclosure (HPBDE) project formed into five committees to establish requirements and identify performance goals for building enclosures. Four of the five committees (Architectural, Structural, Fenestration and Mechanical) represent the broad scope functional enclosure systems. The fifth (Owner) utilized the data on performance identified by the four Technical Committees to establish the methodology for analyzing performance and predicting outcomes.

Committees were made up of small groups of practitioners with demonstrated expertise (committee members are identified in the Foreword and Acknowledgments section). Detailed information on what each committee developed is contained in Chapter 5: Technical Analysis and Chapter 6: The OPR Model Algorithms and Decision-Making Methodology. The purpose of each committee was as follows:

1. **Owner Committee** – The Owner Committee was responsible for establishing the decision-making model that analyzes the multiple demands placed on a building and its potential performance in response to those demands, along with the building owner's program objectives for resilience, risk and operational performance. The committee was charged with creating the conceptual model, working with

> Committees were made up of small groups of practitioners with demonstrated expertise.

the other Technical Committees to capture the technical data about performance in that model, and developing the online tool to help owners establish their performance requirements for the proposed building interactively.

2. **Architectural Committee –** The Architectural Committee was responsible for identifying demands and performance of the architectural systems that comprise the building enclosure in the areas of energy conservation, environment and durability.
3. **Structural Committee –** The Structural Committee was responsible for identifying demands and performance of the structural systems that are part of or impacted by the building enclosure in the areas of safety and security.
4. **Fenestration Committee –** The Fenestration Committee was responsible for identifying demands and performance of fenestration systems that are part of the building enclosure in the areas of energy conservation, environment and sustainability.
5. **Mechanical Committee –** The Mechanical Committee was responsible for identifying demands and performance of the mechanical systems that are part of or impacted by the building enclosure in the areas of energy conservation, environment, security and sustainability.

To identify and analyze high-performance building attributes, participants in the High Performance Based Design for the Building Enclosure (HPBDE) project formed into five committees to establish requirements and identify performance goals for building enclosures.

Each committee held a series of team meetings and established intermediate work assignments to identify and provide values for the components of the OPR Model (see Chapter 3). Throughout this process, each of the Technical Committees focused on developing the components of the OPR Model in accordance with their functional focus, while the Owner Committee developed the methodology that would utilize the values provided by the Technical Committees to weigh the performance of multiple attributes simultaneously. During the meetings, the overall group reviewed and refined the work of the Technical and Owner Committees which led to the subsequent development of the data needed and the complete model for processing the data.

Early in the project, the decision was made to work with the Catalyst Performance Modeling (CPM[2])tool as the platform for automating the OPR. The use of the CPM platform provided the framework for the

2 Catalyst Performance Modeling software is developed by Performance Building Systems (www.performancebuilding.org) for conceptual modeling of buildings.

evaluation of demands and performance using analysis of comparative capital costs for investments, operating costs and total cost of ownership to value and enable comparison of the resulting outcomes.

Upon the completion of the technical analysis and finalization of the OPR Tool design, team members prepared a Project Report and the software developer prepared a test version of the OPR Tool. When these were completed, the Project Team conducted a period of internal review. The review period was used to collect comments on the OPR Model and its components from the Technical Committees. Comments were evaluated and incorporated into the Final Project Report and Release Version 1.0 of the OPR Tool.

Members of the Institute's High Performance Building Council, Building Enclosure Technology and Environment Council and Whole Building Design Guide Board, as well as members of the ASTM Enclosure Committee and Industry Advisory Council of a related DHS IDD project, Retrofit of Buildings in Large Urban Centers, will be invited to review and comment on the completed Report and OPR Tool when they both are released to industry. Comments from other interested parties will also be welcomed. A process for submitting comments will be provided.

3

The Owner Performance Requirements (OPR) Process

The central element of the HPBDE project is a process for evaluating performance tradeoffs between the high level attributes that define a building's function as increasing levels of demands/threats are placed on the building and increasing levels of performance are reached for each attribute. The Owner Performance Requirements (OPR) process is based on a model that relates function, demand, performance and outcomes. The main elements of the model are:

1. **Attributes –** Attributes are high-level properties that define a building in terms of the performance the building is to deliver. As noted earlier, the Project Team decided to use the attributes identified in EISA 2007. These have been further divided into sub-attributes.
2. **Demands or Threats –** These are conditions placed or exerted on a building by its location or exposure to a man-made or natural hazard or condition.
3. **Systems –** The major parts of a building described in terms of their function.

> The main elements of the model are: attributes; demands or threats; systems; performance; metrics; and outcomes.

4. **Performance** – Defined levels at which performance in response to a given level of demand is measured, from Baseline to High Performance.
5. **Metrics** – The measurements of performance of an attribute at a given demand as defined by a standard or best practice.
6. **Outcomes** – The resulting levels of performance expressed in the metric(s) identified for any given combination of demand exerted and performance targeted for the building. These are grouped into three categories by type in the OPR model – Risk, Resilience and Operational.

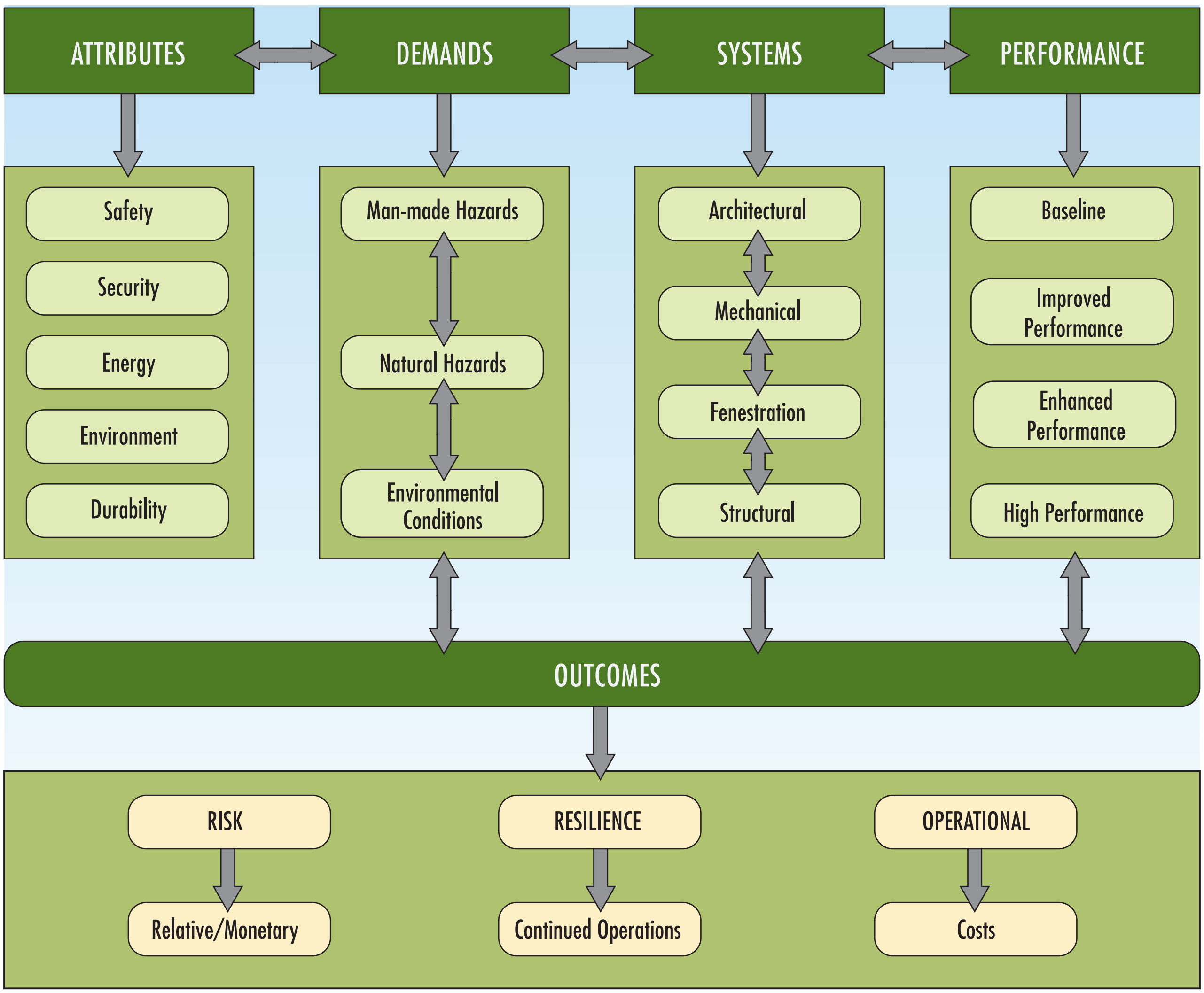


Figure 3-1: Owner Performance Requirements Model

The components of the OPR Model are described in general here. More specific descriptions of the components are provided for each functional part of the enclosure in Chapter 5 and the logic and algorithms used to inter-relate the components is further detailed in Chapter 6.

3.1 Attributes and Sub-attributes

As noted in the Introduction, the project relies on the building performance attributes identified by EISA 2007. The Act identifies eleven attributes that define 'high performance.' At this phase of the OPR development, the Project Team decided to directly address five of the eleven attributes, namely: safety, security, energy conservation, environment and durability. The project also indirectly addresses sustainability through renewable energy and daylighting, which are included with energy conservation in the OPR Model. Also addressed indirectly are cost benefit, which is analyzed for all attributes, and operational (continuity of operations), which is evaluated for safety and security. These were further divided into sub-attributes to align with the measurements relevant to establishing the early planning-level performance requirements for a new building. The table below identifies the sub-attributes that were studied and the functional systems that were evaluated for performance.

Table 3 1 EISA 2007 Attributes and Sub-attributes

EISA 2007 Attribute	Sub-attribute	Functional System
Safety	Seismic Resistance	Structural
	Wind Resistance	Structural
	Flood Resistance	Structural
	External Fire Protection	Structural
Security	Blast Protection	Structural
	External CBR Protection	Mechanical
	Ballistic Protection	Structural
Energy Conservation	Thermal Transfer	Architectural, Fenestration
	Air Tightness	Architectural
	Renewable Energy – Solar	Mechanical
	Renewable Energy – Natural Ventilation	Fenestration
	Daylighting	Fenestration
Environment	Environmental Footprint	Mechanical, Fenestration
	Acoustic Transmission	Architectural
Durability	Water Penetration	Architectural
	Water Vapor Migration	Architectural
	Building Service Life	Architectural

Following is a brief description of the attributes and sub-attributes modeled by the project. The Technical Analysis Chapter includes a definition of each sub-attribute by the functional area/committee that had responsibility for its development.

1. Safety

Safety addresses the ability of the building enclosure to resist natural (or, in the case of flood and fire, potentially man-made) hazards resulting from seismic, wind, flood and/or fire events, and continue to operate. For the HPBDE project, safety evaluation was limited to the enclosure. Fire and flood threats were limited to external events. Interactions of the enclosure with structural systems are included, to the extent that the structural system interactions support the function of the enclosure.

> Safety addresses the ability of the building enclosure to resist natural hazards and continue to operate.

2. Security

Security addresses the ability of the building and its enclosure components to resist man-made threats from external blasts, external ballistics and external chemical, biological and radiological (CBR) releases, and continue to operate. For the HPBDE project, security evaluation was limited to impacts on the enclosure. Threats were limited to external events. Interactions of the enclosure with structural and mechanical systems are included, to the extent that the systems support the function of the enclosure.

> Security addresses the ability of the building and its enclosure components to resist man-made threats and continue to operate.

3. Energy Conservation

Energy conservation addresses the reduction in the use of fossil fuel-generated energy to operate a building for its intended use. For this project, only the portion attributable to the building enclosure was considered. The HPBDE project identified and estimated the performance of thermal transfer and air tightness as sub-attributes of energy conservation directly related to the building enclosure. In evaluating energy conservation, the OPR Tool aggregates the effects of thermal transfer, air tightness and renewable energy into a Net Energy Improvement value to quantify an overall effect on the project. More discussion of this is included in Chapter 4, under the How to Use the OPR Tool section.

> Energy conservation addresses the reduction in the use of fossil fuel-generated energy to operate a building for its intended use.

In the OPR Model, for simplicity in this phase, the EISA attribute of sustainability was evaluated as a part of the energy conservation attribute. Sustainability addresses the ability of the building enclosure to generate renewable energy to offset the use of fossil fuel to operate the building. Sustainability evaluations were limited to components that interface with the enclosure: solar photovoltaic, natural ventilation and daylighting.

4. Environment

Environment addresses the impact that the building and its enclosure components have on the environment and the building occupants' interaction (limited to acoustical interaction) with the environment. The HPBDE project identified and estimated the environmental footprint attributable to the building enclosure from the building's use of energy. In addition, the acoustic transmission performance of the buildings enclosure in resisting externally generated sound levels was estimated as another measure of environmental performance .

Environment addresses the impact that the building and its enclosure components have on the environment.

5. Durability

Durability addresses the building enclosure's ability to withstand the effects of water penetration and water vapor migration while performing without a degradation in function for a specified period of time. For the HPBDE project, durability evaluation was limited to impacts on the enclosure. In evaluating durability, the OPR Tool aggregates the performance levels selected for water penetration, water vapor migration and service life into a Net Operational Improvement value to quantify overall effect on the project. Further discussion of this is included in Chapter 4.

Durability addresses the building enclosure's ability to withstand the effects of water penetration and water vapor migration while performing without a degradation in function for a specified period of time.

3.2 Demands/Threats

Demands or threats placed on the enclosure by natural or man-made forces are modeled in a consistent way to measure response to increasing levels and corresponding increasing levels of enclosure performance by sub-attribute. Demands fall into three categories: natural hazards, man-made hazards and environmental conditions, and correspond directly to the attributes ofsafety, security, energy, environment and durability. This relationship is illustrated in Figure 3-1.

Two types of demand models are used to capture demand behavior:

1. **Multi-dimensional** – The behavior of two variables is identified at three or four levels and the resulting demand at the intersection of the independent demands is characterized relatively. For example, for blast, three levels of stand-off distance from the building and explosive charge strength are identified and the resulting combination of demands are characterized as High, Medium or Low (e.g. a short standoff distance and strong charge strength would result in a High threat). The Blast Demand model is fully shown in the Structural Analysis section 5.2.
2. **Single dimension**– a single variable is used to specify demand based on a given criteria. For example Seismic Design Category (SDC) as defined by the American Society of Civil Engineers is used to determine level of potential seismic activity where the building is located. Alternatively a demand level may be selected as High, Medium or Low from a controlled list of choices.

Specific demand models for each Sub-attribute are identified in the Technical Analysis sections.

3.3 Systems

The evaluation of the enclosure in this phase covers the exterior walls above and below grade including opaque and glazed surfaces and the roofing system. Interactions of the enclosure systems with the structural system as is required to support increasing levels of demand and performance are evaluated. Similarly impacts of demands/ loads on the mechanical system are evaluated with respect to estimating the portion of the whole building energy consumption attributable to the enclosure. In addition, the level of protection provided by the mechanical system in resisting externally released CBR substances from penetrating through the building enclosure is evaluated. It is anticipated that subsequent phases of the project will expand the analysis to include the complete structural system, the complete mechanical system and the electrical system.

> The evaluation of the enclosure covers the exterior walls above and below grade including opaque and glazed surfaces and the roofing system.

As noted in the Overview, this phase of the project is limited to a single building type, commercial office buildings. Subsequent phases of the project will progressively expand to cover additional building types.

The technical analysis considered performance of a range of system types and some that were referenced by the committees to establish performance for a sub-attribute are identified in each section. Similarly, while specific systems were referenced to establish baseline costs, these values were then distributed to a range to cover the whole spectrum of available design solutions to satisfy a demand and performance level selected. The systems evaluated to determine the impact of increasing levels of demand/threat and corresponding increasing levels of performance are the following.

1. **Basement Walls** – Exterior walls to enclose the basement of the building including moisture proofing and drainage.
2. **Roof Structure** – Roof structural framing including decking materials.
3. **Exterior Opaque Walls** – solid surface materials used to construct exterior walls.
4. **Fenestration** – window, storefront and curtain wall systems used to enclose a building and provide light to interior spaces.
5. **Roofing System** – roof covering membrane, insulation, fastening system, openings, penetrations and flashings include edges.
6. **HVAC System** – whole building HVAC system to maintain the comfort and health of building occupants.
7. **Solar Energy Generation System** – roof mounted photovoltaic panels and distribution system.

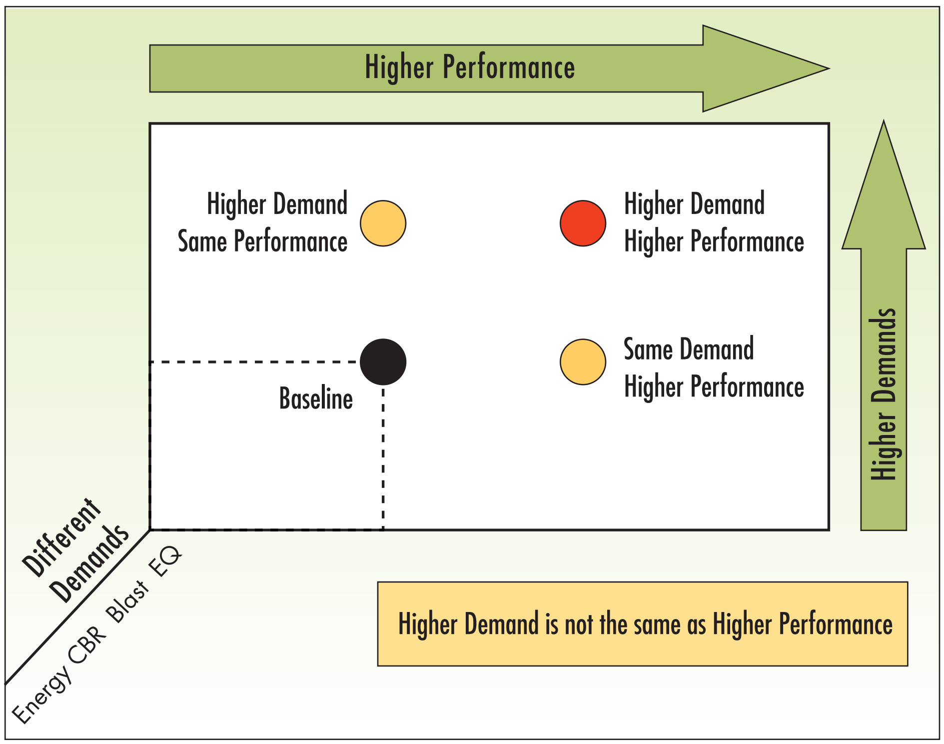
To establish the baseline costs of each system, three levels of quality as defined by the Building Owners and Managers Association (BOMA) organization were used:

- **Quality Level A: Class A** – Most prestigious buildings competing for premier office users with rents above average for the area. Buildings have high quality standard finishes, state of the art systems, exceptional accessibility and a definite market presence.
- **Quality Level B: Class B** – Buildings competing for a wide range of users with rents in the average range for the area. Building finishes are fair to good for the area and systems are adequate, but the building does not compete with Class A at the same price.
- **Quality Level C: Class C** – Buildings competing for tenants requiring functional space at rents below the average for the area.

3.4 Performance Levels

The heart of any performance-based design is the complex interrelationship between demand and performance. On a basic level, it is recognized that levels of demands on buildings can range from low levels to high levels. In the OPR model, demands mean any type of design condition that is placed on a building as discussed in the previous section on Demands. Similarly, performances can range from low performance to higher performance. The demand-performance spectrum is shown in Figure 3-2.

Figure 3-2: Demand-Performance Spectrum



The demand-performance spectrum in the OPR is designed to cover as much of the range of high performance as possible and as is relevant to the limited scope of the building enclosure only. Diverse performance metrics are needed to capture the wide range of the EISA attributes' performance and translate them into how buildings are designed to deliver performance. For example, expressing the ability of a building to respond to unpredictable safety and security demands vs. predictable energy conservation demands, while at the same time also inter-relating these demands, is made possible. Capturing such diversity offers powerful decision-making tools for the user.

To achieve this, attribute performance is modeled at four increasingly higher levels by the OPR model for Operational and Resilience performance:

1. **Baseline –** performance with no special levels of demand or enhancements to systems above "code minimum" performance.
2. **Improved Performance/Resilience (P +/Re+) –** one level of enhanced performance above the Baseline to meet an identified performance standard or produce a defined outcome.
3. **Enhanced Performance/Resilience (P++/Re++) –** two levels of performance above the Baseline to meet an identified performance standard or produce a defined outcome.
4. **High Performance/Resilience (HP/HRe) –** the highest level of performance achievable with available technology.

Performance outcomes are established in two ways in the OPR process; as high level targets for three Project categories; and directly as outputs at the sub-attribute level. The Project Categories are interrelated with the sub-attribute levels such that a Project level performance target determines corresponding sub-attribute performance levels. However, these pre-defined relationships can be overridden by the user of the OPR Tool. Doing so may lead to changes in targeted Project performance levels. The process works this way to allow the Owner to initially set targets for overall performance for only three variables that can later be refined by sub-attribute output performance level selections.

Project Performance Categories are:

1. **Resilience –** a function of Robustness, Resourcefulness and Recovery is a product of quality of function loss and the time to recover. For comparative purposes the model calculates resilience based on cost and time to recover from an event.
2. **Risk –** is a function of the probability of hazard occurrence, hazard level, and the resulting consequences or outcomes. Risk is calculated by the model based on demand/threat levels and sub-attribute performance levels identified.
3. **Operational –** is a function of performance level and resulting outcomes from that performance level at a given demand level.

Each of these three performance metrics is subdivided into four levels as shown the following table.

Table 3-2: Project Performance Metrics

Project Performance Metrics		
Operational	**Risk**	**Resilience**
Operational Baseline	Risk Baseline	Resilience Baseline
Improved Performance (P+)	High Risk (HRi)	Improved Resilience (Re+)
Enhanced Performance (P++)	Moderate Risk (Ri–)	Enhanced Resilience (Re++)
High Performance (HP)	Low Risk (Ri-)	High Resilience (HRe)

Sub-attribute performance metrics are of two types:

- **Qualitative –** identification on a relative scale established based on judgment/experience. For this project, resiliency and risk are scored on a qualitative scale from 0-10. The scores are derived by the OPR Tool based on values for selected user inputs that have been scored by the HPBDE model. These apply to the safety and security attributes. Qualitative metrics are useful to provide a feel for the order of magnitude of the metrics. However, they are most useful in comparing different outcomes within the same project. A scenario with a risk rating of 5 is better than a scenario with a risk rating of 7, for example.
- **Quantitative –** having an expression of performance that can be calculated. These can be absolute values expressed in monetary units such as absolute risk (expressed as Exposure in the OPR Tool described later in this report) or life-cycle values shown using monetary units on a time scale, such as energy costs.

3.5 Metrics and Outcomes

For each sub-attribute a metric is identified to measure performance achieved at each benchmark level. Metrics are based on an industry standard if available or a best practice as defined during the technical analysis. The individual standards and practices are identified and defined in the Technical Analysis chapter and summarized in Appendix A. For each metric, anticipated outcomes for any combination of demand or threat level and performance benchmark are established by the model. Outcomes might be qualitative or quantitative. Qualitative and quantitative outcomes are identified for each sub-attribute in the Technical Analysis chapter and are used to identify the Owner's Performance/Project Requirements for any given building enclosure scenario that is modeled.

Qualitative outcomes describe performance anticipated such as *No glass cracking will occur.* Quantitative outcomes provide a measurable performance level such as air tightness of *0.2 CFM/SF@75Pa*.

A common quantitative metric used throughout is cost.

A common quantitative metric used throughout is cost. Cost outcomes are established for capital costs to acquire, upgrade to increase performance, or replace a system; operating costs for energy or other consumables; Maintenance costs for keeping systems operational for their specified life; and replacement costs for removing and replacing a system in response to a failure event.

The following graphic illustrates the relationship between Attributes, Demands and the Metrics that quantify Performance.

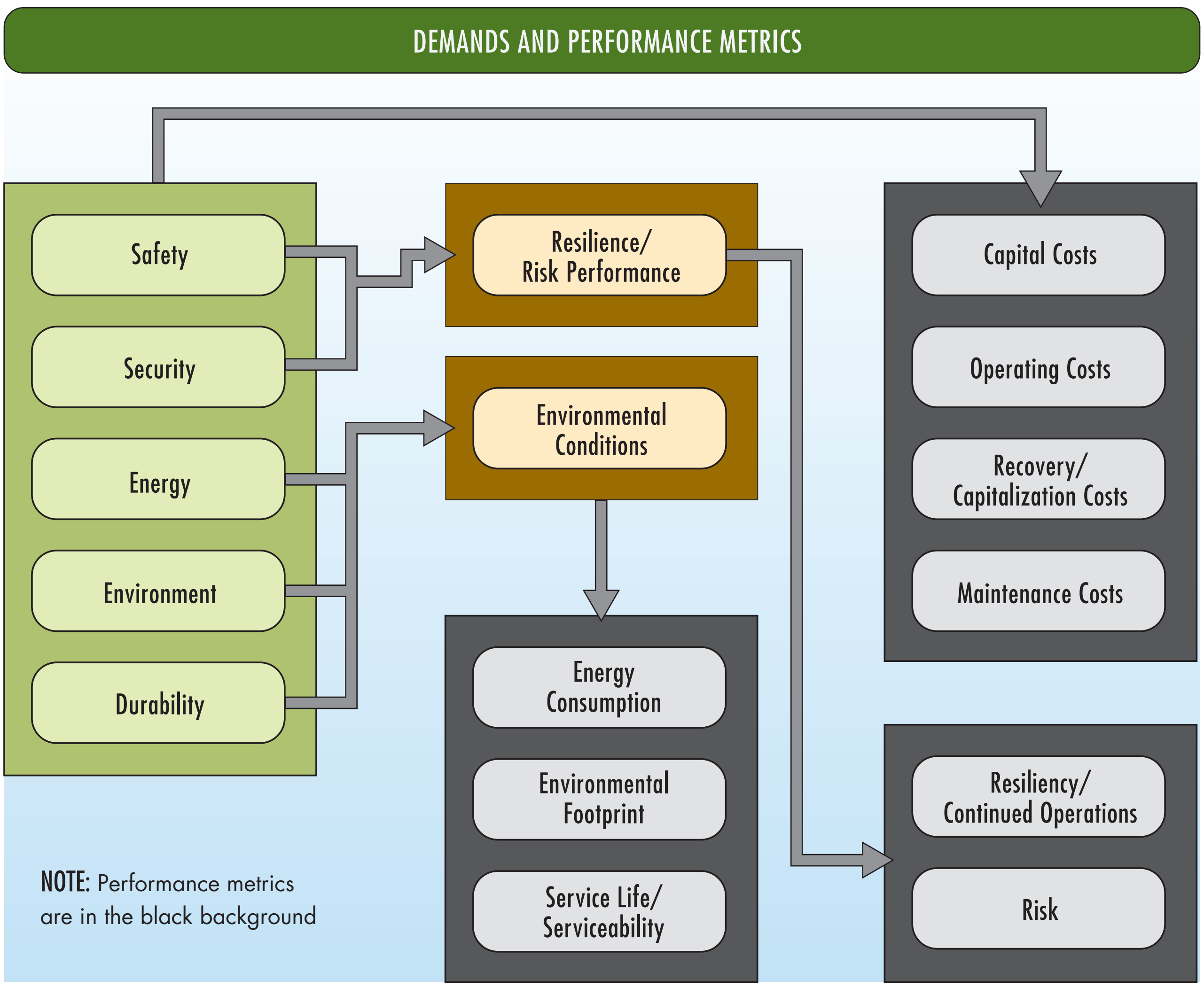


Figure 3-3: Attributes Demands and Performances

3.6 Processing the Model

The basic premise of the OPR process is that the building owner will choose certain target levels of building performance and certain levels of demands to be placed on the building. Then, through a set of rules, an optimization process is performed and the expected results (outcomes) are computed. The outcomes resulting from the optimization process might not all be the ultimate ones desired. The user can then adjust the target performances, or demands for the building and repeat the process. This iterative process would continue until acceptable results are attained. The combination of demands/ performances that produce acceptable results can then be used as the basis for the design process of the building.

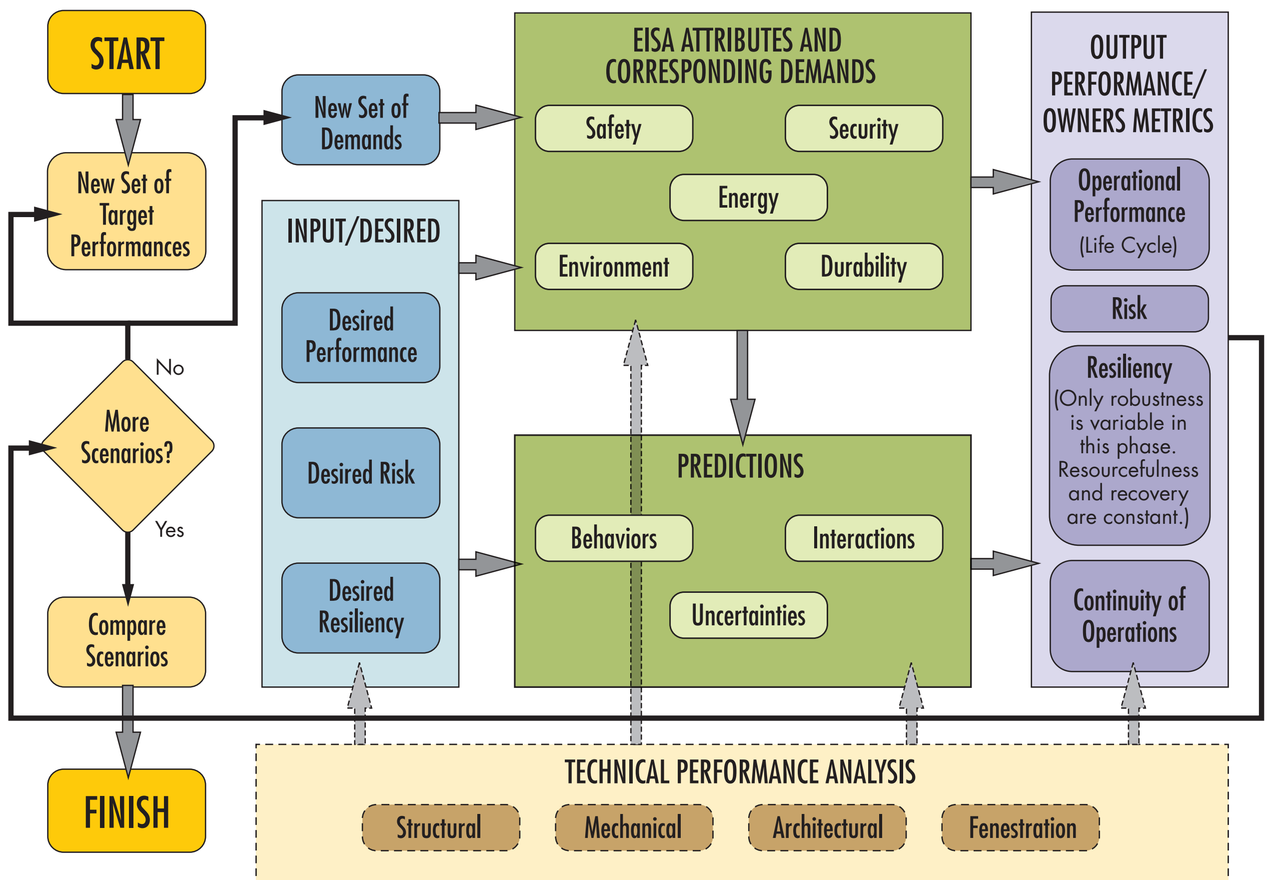


Figure 3-4: OPR Model processes

The different OPR processes and their interrelations are shown in Figure 3-4. This process is automated for the owner in the OPR Tool. How the Tool is used to calculate and compare results is described in detail in the following Chapter.

4

Owner Performance Requirements (OPR) Tool

A key component of the HPBDE project is the creation of a tool that automates the OPR process and allows for the evaluation of enclosure performance criteria for a proposed project. How the OPR Tool[3] fits into the Planning process, how the Tool works and how it can be used by a building owner to analyze alternatives is covered in this Chapter.

4.1 The OPR Tool in the Planning and Design Process

The OPR Tool allows building owners or anyone considering a proposed project to perform an evaluation based on the full range of underlying performance objectives that best meet their needs. Using the OPR Tool, each component of performance can be evaluated against a corresponding range of potential demands to make decisions about the optimal set of objectives for the intended

3 Note: The tool is named the Owner Project Requirements Tool on the website to reflect its use to plan projects and align it with the naming used for this component of the commissioning process.

A key component of the HPBDE project is the creation of a tool that automates the OPR process and allows for the evaluation of enclosure performance criteria for a proposed project.

use and location of the project. The OPR Tool allows the consideration of alternative configurations to enable comparisons so that a proposed configuration for a project can be tested against alternatives. Evaluation is made using cost as the common metric to analyze and compare alternatives. Translating performance to the range of costs to deliver a given level of performance was a key contribution of the Technical analysis described in Chapter 5.

To enable this comparison, the OPR Tool uses estimates of the capital cost for the systems that deliver the expected benefits from achieving a targeted level of performance in terms of reductions in life cycle or recovery costs. Estimates for capital investment cost and corresponding total cost of ownership are generated for any given scenario evaluated.[4] These are the yardsticks that allow a user to select the best combination of requirements for their proposed project. Corresponding to the combination of demands and performances chosen, a set of performance objectives is produced that can be provided to the design team to guide them in achieving the performance levels established in the OPR modeling process.

To accomplish this, the OPR Tool employs a performance-based parametric computing and modeling approach, instead of the more traditional design-based (or systems-based) approach. In the Performance-based planning process, the Owner's Performance Requirements are established early in the planning process, rather than as an outcome of a particular system selection and design. As a result the evaluation process can be compressed and multiple alternatives can be tested in less time – providing a valuable time and cost benefit to an owner.

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4 The processes of comparing the results from a given set of demands / desired performances are called scenario comparisons. The scenario comparison section of the OPR tool is described later in this chapter.

Applying the OPR Tool in the early planning and pre-design stages of a project does not recognize or consider particular design solutions. This is another primary benefit of using the tool, for when the project enters into the design phase; the design team has greater freedom and exercise of creativity to design solutions that meet the performance outcomes generated by OPR Tool that the Owner has determined fit the needs for the project.

This section will explain how the Tool works, what it generates for results and how to evaluate those results so that the owner can understand and use it for project planning with confidence in its logic and function.

4.2 Using the OPR Tool

The OPR Tool is a simple to use, web-based application. It was developed in a series of integrated worksheets that contain the data elements of the OPR Model for Operational, Risk and Resilience performance created for establishing and analyzing the Owner Performance Requirements. The OPR worksheet model was then programmed into a relational database which underlies the OPR Tool. Access to the OPR database is provided through a web interface that was created to allow users to interact with the model. Through the Tool, inputs describing a proposed project are made by the user and then processed by interacting with the OPR database. Access is available at www.oprtool.org.

To start using the tool requires registering at the site and providing basic contact information. With an account established, use of the tool to evaluate the enclosure systems for a proposed project follows a step-by-step process as described here. During the process, values for a range of parameters are set both by the system based on direct relationships in the OPR model and by the users. The Input parameters uses in the OPR Tool are listed in Table 4-1.

> The OPR Tool is a simple to use, web-based application. It was developed in a series of integrated worksheets that contain the data elements of the OPR Model for Operational, Risk and Resilience performance created for establishing and analyzing the Owner Performance Requirements.

Table 4-1 Input Parameters

Category	Parameter
General Project Information	Gross Building Area
	Quality Class
	State and City Location
Project Performance Benchmarks	Operational Performance
	Resilience Performance
	Risk Level
Life Cycle Information	Use Period
	Unit Energy Cost
	Service and Maintenance Cost
	Escalation Rates
	Discount Rate
	Occupancy Information
	Indirect Project Costs
Facility Resilience Information - Safety	Seismic Design Category
	Flood Plain
	Flood Depth
	Flood Velocity
	Wind Speed
	Wind Exposure
	Tornado Protection
Facility Resilience Information - Security	Blast Charge Strength
	Blast Range/Proximity
	Ballistic Threat Level
	CBR Agent Type
	CBR Exposure
	CBR Range/Proximity
Facility Operations Information	Exterior Glazing Percentage
	Air Tightness/Leakage
	Daylighting
	Natural Ventilation
	Solar Energy
	Water Penetration
	Water Vapor Migration
	Service Life
	Outside Sound Level
	Acoustic Benchmark Level

4.2.1 Input Information

The first step for a user is to set up a project; the next step will be to name a Scenario and then proceed through the input selections. There are four stages of input: Scenario Information, Life Cycle Information, Facility Resilience and Facility Operations:

There are two key groups of project information– General Scenario Information and the Overall Owner Performance Benchmark.

Project Information

There are two key groups of project information– General Scenario Information and the Overall Owner Performance Benchmarks. Note that this first version of the OPR Tool is for office buildings and new construction only. Upcoming versions will include a range of additional selections relevant to different building types and new vs. renovation of existing buildings.

1. **General Scenario Information:**

   Scenario Name and Type – provide a meaningful name to the Scenario keeping in mind that multiple (up to 4) scenarios can be established for analysis within any project. As noted above, Type selection will apply in subsequent versions.

   Gross Building area and Total Floors Including those below grade – select values from the lists provided to inform the computation of project size parameters such as roof, opaque wall and glazing areas by the tool.

   Quality Class – three selections: A, B and C – based on BOMA building quality classes.[5] This establishes the baseline values for the whole building and system categories (Roofing, Exterior Wall, etc.) for service life and also level of capital expense values.

   State and Metro Area – select the closest location for the project from the drop-down list. These are mapped to the local cost index and also the climate, both of which are key parameters in establishing the baseline costs and thermal and water related demands on the building

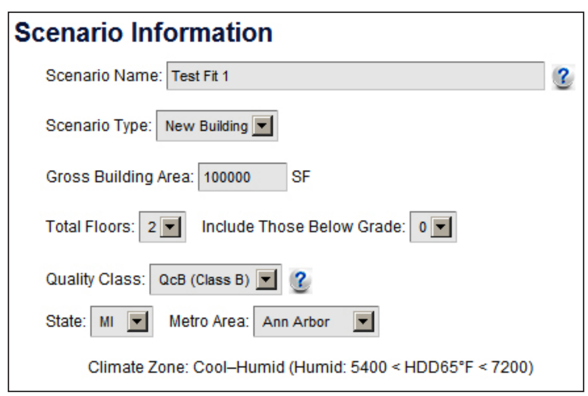


Figure 4-1: Building Parameter Input

5 Building Owners and Managers Association International (BOMA) has established three levels of quality for commercial buildings that are widely accepted in the industry. Explanation of these can be found at www.boma.org/Resources/classifications.

2. **Project Performance Benchmarks** – three high level targets for project performance are selected by the user:

   Operational Performance – This establishes the overall facility performance associated with normal, ongoing operation of the facility. The benchmark selections for Operational performance are selected from a drop list as shown in Figure 4-2 below.

   Resilience Level – This establishes the overall facility resilience associated with a safety (seismic, wind, fire or flood) or security (blast, CBR or ballistic) event. The benchmark selections for Resilience performance are selected from a drop list as shown in Figure 4-2 below.

   Risk Level – This establishes the overall facility risk associated with a safety (seismic, wind, fire or flood) or security (blast, ballistic, CBR) event. The benchmark selections for Risk performance are selected from a drop list as shown in Figure 4-2 below. The Project Risk Performance level determines the default Performance levels for the safety and security attributes.

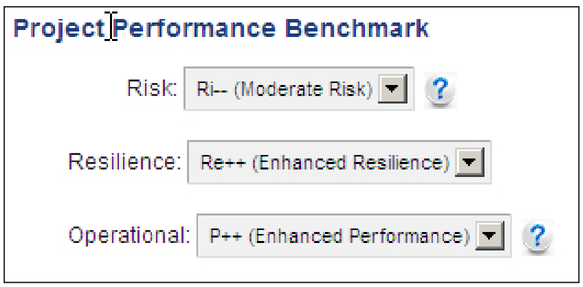


Figure 4-2: Project Performance Benchmark Selections

Life Cycle Information

For the OPR Tool to compute the equivalent Total Cost of Ownership (in this version only that which is associated with the enclosure), there are a number of owner selections needed. Default values are established as a starting point by the model. However, each one should be examined and revised as desired by the user.

1. **Use Period** – The period over which the user evaluates Total Cost of Ownership and Facility Operation (not the same as the Service Life of the facility).

2. **Unit Energy Cost** – A blended rate for electricity and other fuel sources measured in dollars/thousand British Thermal Units ($/KBtu) delivered to the site expected in the first year of operation. Default values are estimated from project location and a DOE table of energy mix by region referenced in the Mechanical section 5.4 and included in the Mechanical Appendix D.

3. **Service and Maintenance Cost** – A value to account for climate and enclosure wear is estimated as a percentage of initial capital cost for a system on an annual basis, expressed in dollars/square foot of gross building area ($/GSF). This is acknowledged to be a gross approximation in this version, pending a future version that includes the

whole building where this can be calculated more accurately for a complete structure.

4. **Escalation Rates** – The average or trend rate of increase in annual costs over the Use Period, which can be applied to Maintenance and Operations, as well as Energy, in this version of the tool.

5. **Discount Rate** – This should reflect the owner's "time value of money" and is used to bring the annual operating costs to a Net Present Value (NPV) for comparison with the other components to the Total Cost of Ownership.

6. **Occupancy Information** – The Average Census (GSF/occupant) enables outcomes to be expressed as a function of the occupant count. The facility operating hours are important in predicting energy consumption

7. **Indirect Project Costs** – In order to get an accurate capital cost that the owner will incur, the indirect costs associated with building professional services (including design) and construction services (including general conditions), can be set by the user.

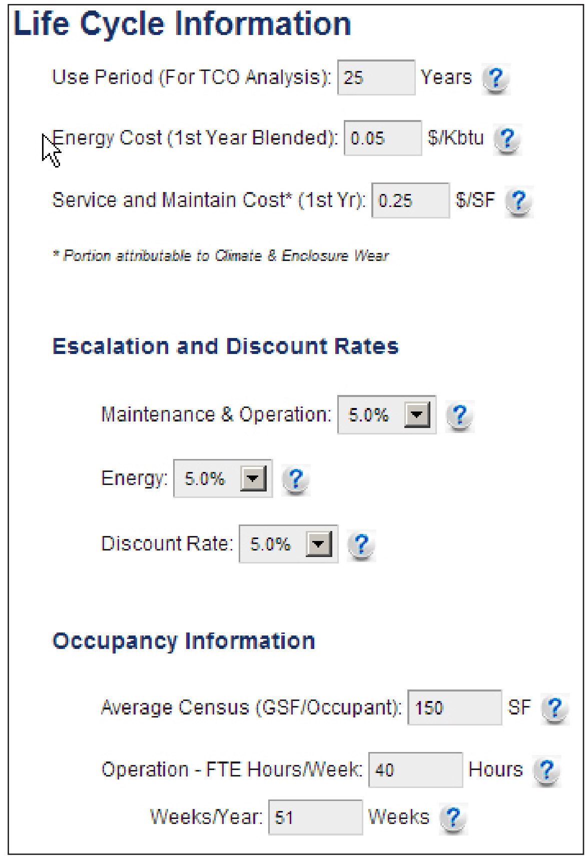


Figure 4-3: Life Cycle Information Inputs

Facility Resilience and Risk Information

The safety (seismic, wind, flood and fire) and security (external blast, CBR and ballistic) benchmarks are initially established based on the Project Performance Benchmark selections. The sub-attribute performance targets derived from the Project Performance targets selected are identified, but can be over-written by the user to reflect more specific needs. It should be noted that these changes will not change the overall Project Performance targets originally set for resilience and risk. Demand levels for each sub-attribute need to be selected by the user from the drop lists provided to establish the level of demand and threat that the building is expected to face. Discussion of the demands and threats modeled is in the Structural Analysis section 5.2.

1. **Seismic Design Zone** – The seismic design category for the planned project location based on severity and frequency for a given location from American Society of Civil Engineers (ASCE) design tables.

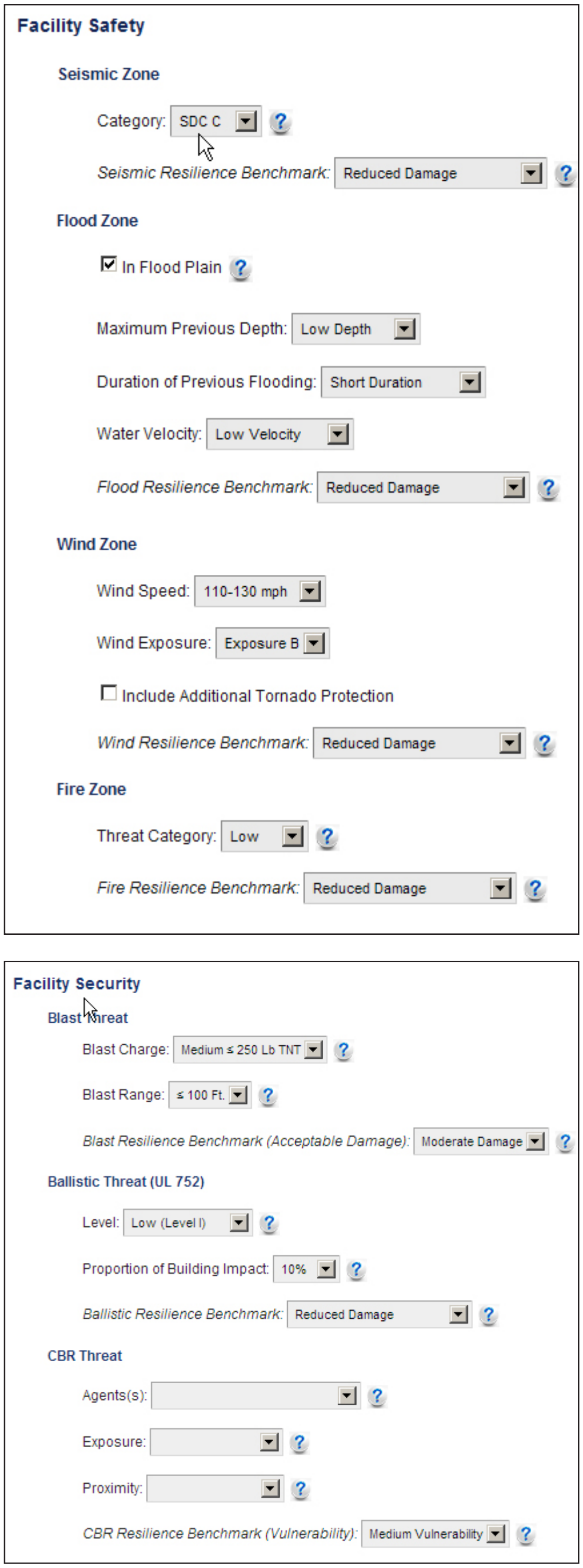


Figure 4-4: Safety and Security Inputs

2. **Flood Zone –** Location of the proposed building in a known flood plain and the anticipated maximum previous flood depth, anticipated duration and potential water velocity at the site from Federal Emergency Management Agency (FEMA) design tables.
3. **Wind Zone –** The anticipated wind speed at the site and the exposure category of the building to that wind as defined in ASCE design tables 7-05 and 7-10. A check box for tornado protection for buildings in tornado prone areas is provided.
4. **Fire Zone –** A subjective self rating based on the building's potential exposure to external fire threats at the site.
5. **Blast Threat –** The charge strength and proximity to the building for which protection is required.
6. **Ballistic Threat –** Potential threat from a firearm as defined in Underwriters Laboratory Standard 752.
7. **CBR Threat –** The type or types of contaminants (chemical, biological and radiological) from which protection is required, the extent of exposure (or concentration), and the release proximity.

Facility Operations Information

Individual sub-attribute performance targets, as established by the selected Project Performance Benchmark are identified and can be edited. There are also a number of demand selections required:

1. **Exterior Glass Portion –** This is a vital parameter of the building enclosure configuration that can be changed from the default percent of glazing to whatever level is desired.

2. **Daylighting, Natural Ventilation and Solar Photovoltaics (PV)** – these sub-attributes/solutions can be selected in most cases. However, in some scenarios where sub-attributes, demands or baseline project information may be mutually exclusive, editing the default value is not enabled (e.g. natural ventilation cannot be selected when CBR protection is a goal).

3. **Water Vapor Migration** – this sub-attribute does not have varying standards of performance. It is at a moisture content of < 80% relative humidity (RH)for all increased performance levels above baseline.

4. **Acoustics** – The user must select both the Outside Sound Impact category and the Interior Noise Isolation level desired. This is the performance benchmark for acoustics and, unlike other benchmarks; its level must be set by the user because it is independent of other Operational Performance sub-attributes. In many cases, there is only a portion of the building that is more sensitive to exterior sound intrusion; in which case, the user can identify that portion and the selected performance upgrades will be applied proportionately.

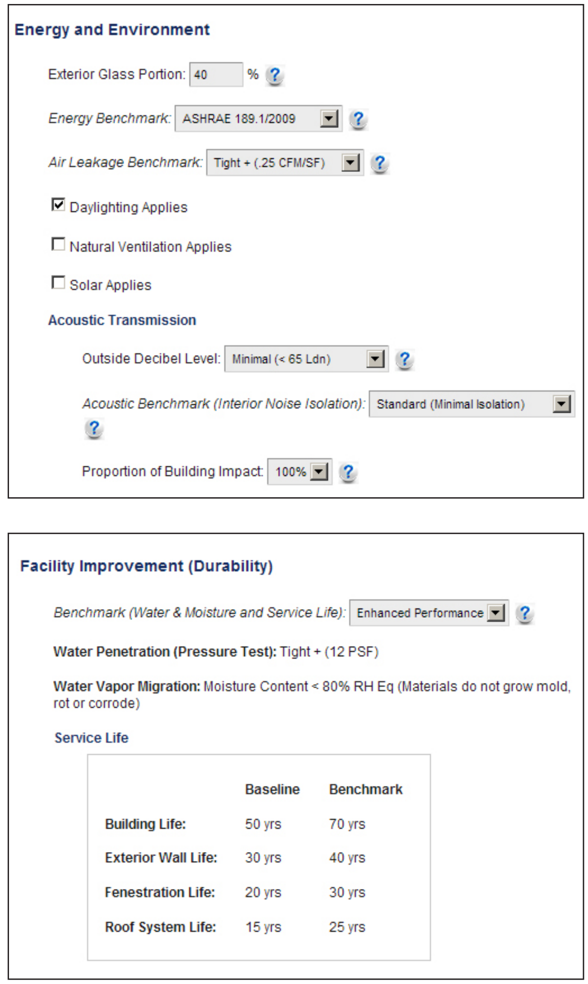


Figure 4-5: Facility Operations Inputs

4.2.2 Output of Results

For each scenario there are two sets of outputs generated from the model by the OPR Tool – a series of dashboards and tabular reports. An explanation for each dashboard follows its sample screen shot. In the dashboards, the following metrics and corresponding units of measurement are used.

Table 4-2 Output Metrics

Metric	Unit	Description
Capital Expense (CapEx)	$/SF	Dollars($)/Square Foot of Gross (G) building area or enclosure system for an upgrade or replacement over the Use Period
Annual Savings (NPV)	$/SF	Net Present Value of savings over Use Period
Return on Investment (ROI)	%	Percentage return from incurring Capital Expense to receive a benefit – Annual Savings
Total Cost of Ownership (TCO)	$/SF	Summation of all costs incurred (baseline and upgrades) and benefits received over the Use Period, returned to a net present value from upgrading systems to meet specified demands/threats
Exposure	$/SF	Cost of the obligated annual operating expenses of mitigation measures taken, plus the cost of recovering from the occurrence of an event
Energy Consumption	KBTU/SF	Thousand British Thermal Units of Energy consumed per Square Foot of Gross building area over the Use Period
Environmental/ Carbon Footprint	CO_2e/SF	Equivalent amount of carbon produced into the atmosphere for the performance levels selected per Square Foot of Gross building area over the Use Period

Dashboards

Graphs from each OPR dashboard report are explained in this section. Descriptions of the results presented and guidance for interpreting the results follow each dashboard screen capture.

Project Benchmarks

A graphic representation of the Project Level Performance Targets selected is provided for Resilience (Improved, Enhanced and High), Risk (Low, Moderate and High), and Operations Performance (Improved, Enhanced and High). Colors are used to further illustrate the level in accordance with the key provided on the dashboard. For each benchmark dashboard screen, the sample results are evaluated in the following sections to illustrate how the output can be used to optimize investment, return and objectives.

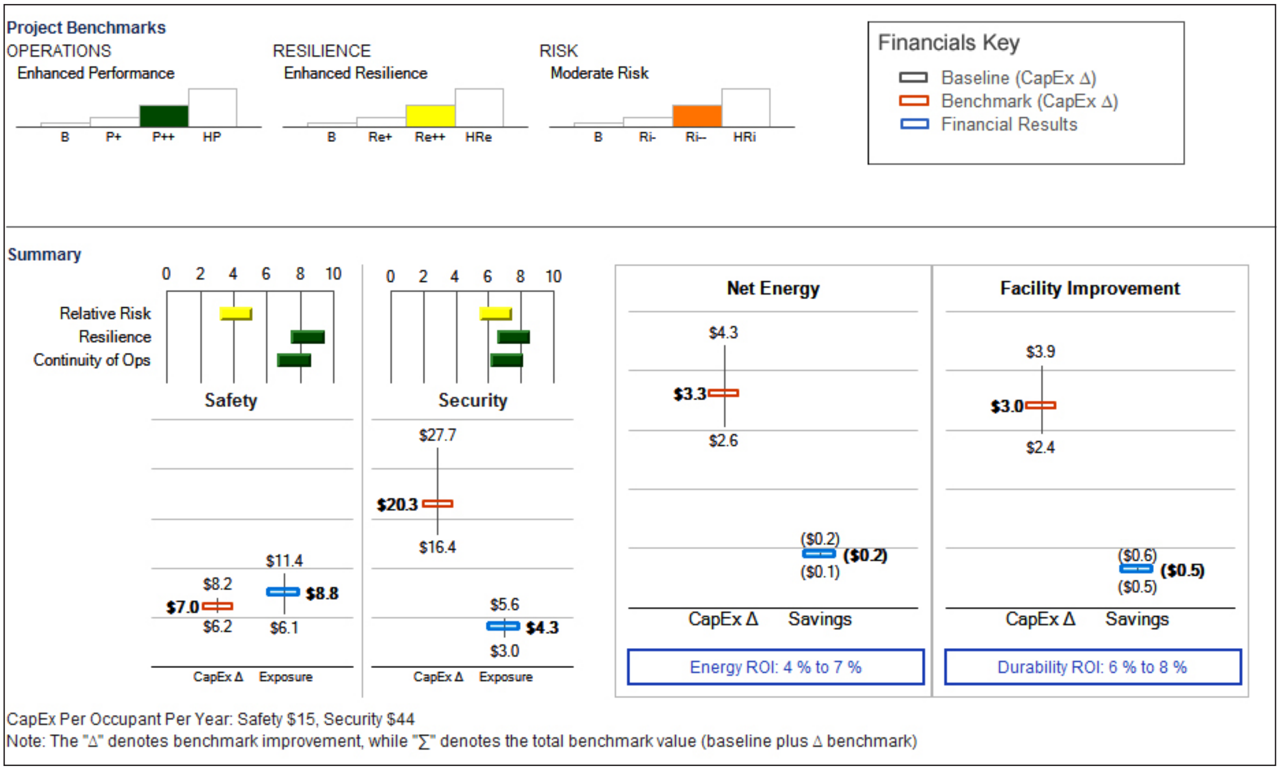


Figure 4-6: Summary Dashboard

Summary

Results for safety and security outcomes are represented in two ways.

1. Qualitatively in three measures based on a scoring system contained in the OPR Tool that assigns values from 1 – 10. A score, from a subjective assessment of the information provided by the user regarding safety and security benchmarks and demands for the project is produced within a range represented by the length of the bar shown in the chart. The scoring system is further described in Chapter 6 section 6.2.2.
   a. Risk (Low is green, High is red)
   b. Resilience (Low is red, High is green)
   c. Continuity of Operations (Low is red, High is green)
2. Quantitatively in two measures: CapEx is the cost ($/SF) to upgrade the building from a non-protected state, to the selected Resilience/Risk benchmark; and Exposure is the resulting financial outcome which includes the annual operating cost incurred as a result of the upgrade, plus the aggregate value of the consequence (cost to remove/repair the affected components not including loss of operations) of a safety or security event(s) occurring in the specified Use Period.

Results for Facility Operations outcomes are expressed quantitatively for both Net Energy (aggregation of energy conservation sub-attributes) and Facility Improvement (aggregation of durability + acoustic). The CapEx, is the cost ($/SF) to upgrade the building from a baseline state to the selected Operations benchmark. The Annual Savings (Net Present Value Equivalent) represents the cost savings from the selected upgrades in response to the identified demands. These two metrics then result in an expected Return on Investment (ROI) range for the upgrades over the Use Period of the project.

Interpretation of Summary Dashboard Sample Results

1. **Safety Summary –** The yellow (medium) bar for the qualitative Risk score indicates that threat levels are expected, but the green Resilience and Continuity of Operations bars show that the building has been hardened to mitigate the risk to a significant extent. The financial results show the Exposure (cost of recovery in the case of a peak natural event) is higher than the Capital Cost of the hardened building. In general the capital expense and exposure should be better balanced (closer to each other in cost). Since the selected Resilience benchmark is "Enhanced" (Re++), it would be advised to re-run the simulation at High (HRe) to see if the added expense is warranted to better balance the Exposure.
2. **Security Summary –** The same conclusions hold true for Security as for Safety, except that the capital expense far exceeds the exposure. This would lead the user to try out different (lower) standards of resilience for some of the security attributes in an attempt to better balance investment with consequence.
3. **Net Energy and Facility Improvement Summary –** The benefits of an improved facility are reflected financially in terms of Return on Investment (ROI) over the Use Period. The Energy savings pertain to the predicted change in annual expenses, whereas the Facility Improvement pertains to avoidance of removing and replacing building systems across the life of the facility. The benchmark levels can be adjusted to balance acceptable first cost with ROI. Inputs for energy costs, escalation and discount rates affect these values and might also be adjusted.

The Capital Expense pie chart shows the relative first cost of upgrading the facility Operations and Resilience, each as a percentage, in comparison to the baseline facility with no upgrades. The financial graph places all four groups of CapEx and resulting benefits over the specified Use Period in terms of ROI on the same scale. This provides a useful comparison of upgrade costs and resulting anticipated benefits for the high level performance categories evaluated.

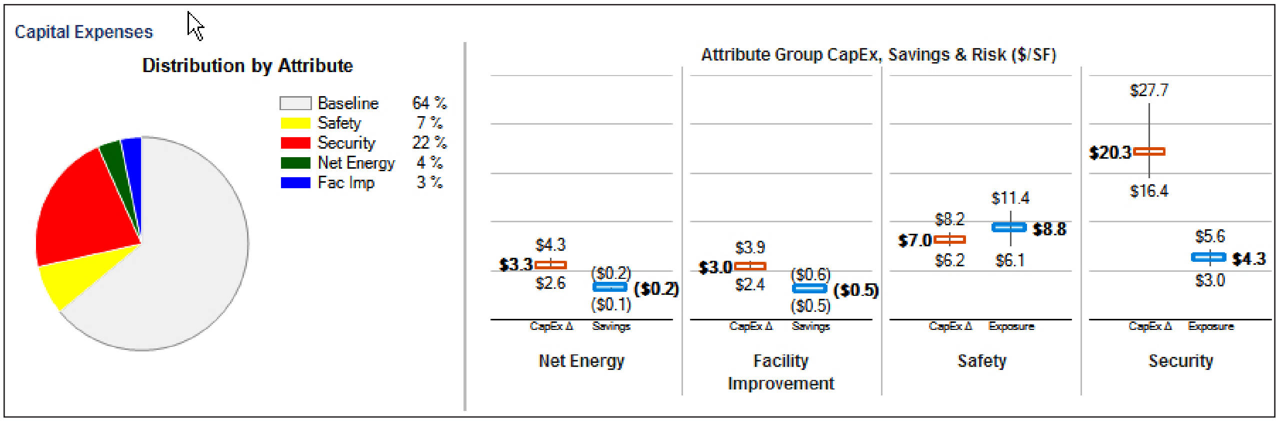


Figure 4-7: Capital Expense Dashboard

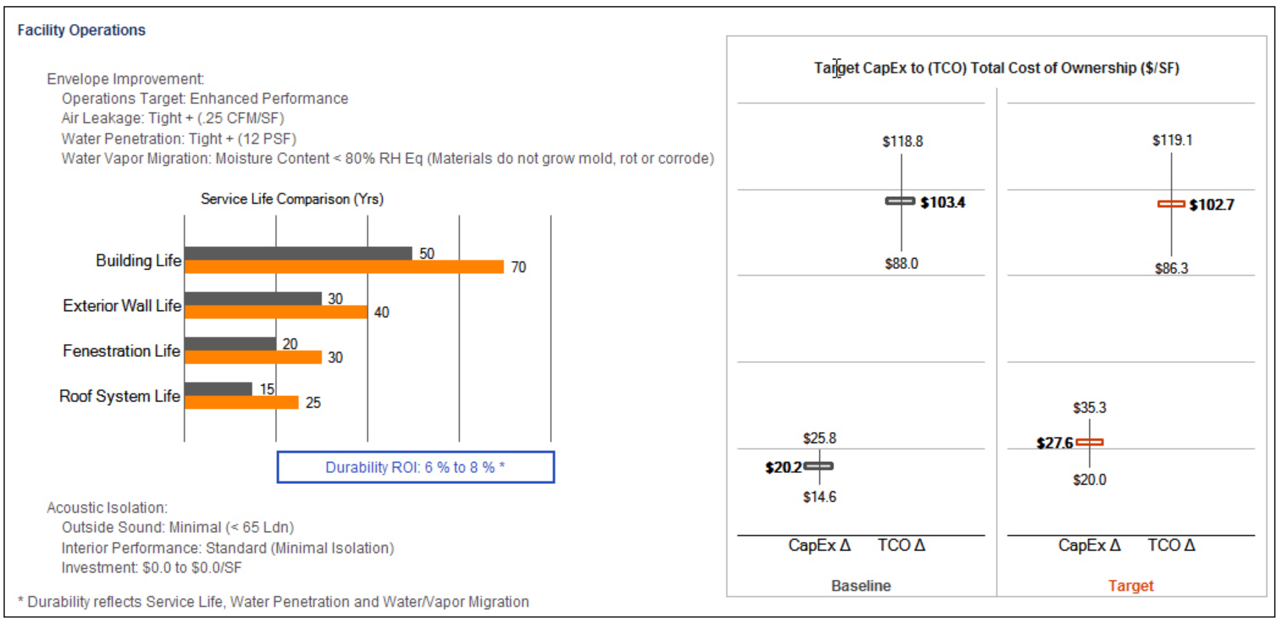


Figure 4-8: Facility Operations Dashboard

Facility Operations

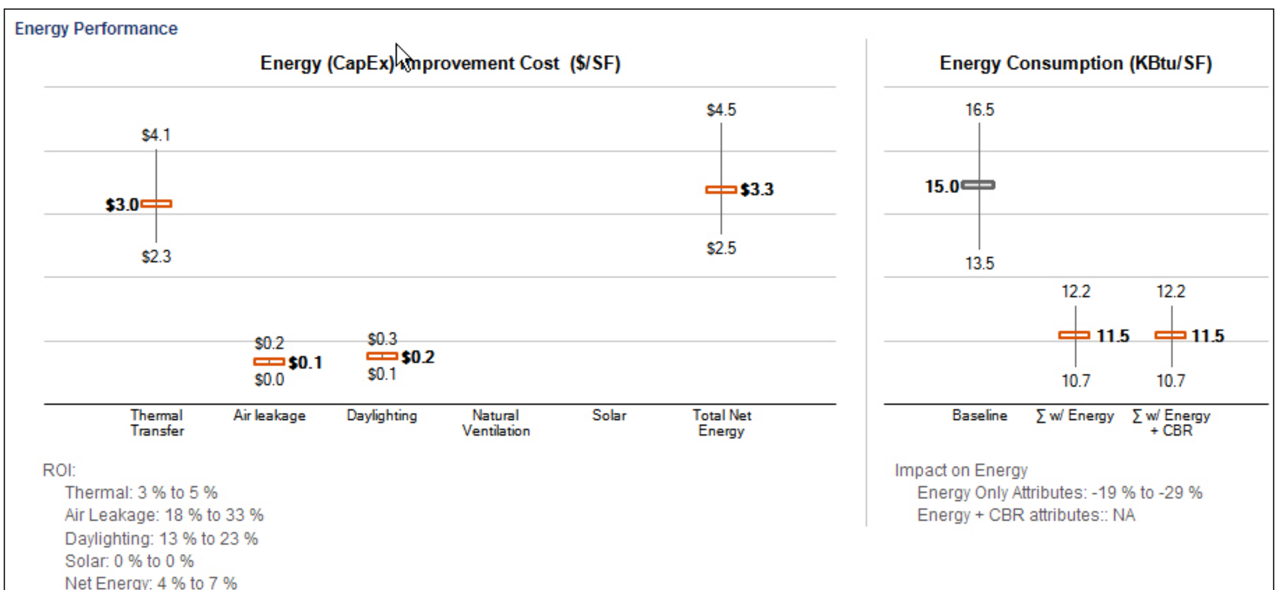
The Enclosure Improvement section summarizes the performance levels and shows the improvement in service life of the whole building as well as the enclosure systems. Taken over the life of the facility and based on the recapitalization costs as a result of replacing systems, a Durability ROI is computed. The Acoustic Transmission summary includes the demand, performance and capital cost.

The Target CapEx to Total Cost of Ownership (TCO) shows a comparison of both values from the baseline to the selected benchmark (Target), not including any of the safety and security upgrades selected.

Interpretation of Facility Operations Sample Results

1. **Service Life Comparison** – The baseline (grey) building Service Life of 50 years is increased (orange) to 70 years when upgraded to the selected benchmarks for the whole building, together with respective enclosure component upgrades. The ROI on the investments in Durability is also shown and in this case indicates that the investments will have a modest payback over the Use Period perhaps warranting some adjustments of 6% to 8%.

2. **Total Cost of Ownership (TCO)** – Generally, an increase in mean capital expense to upgrade a facility (in this case from $20.20 to $27.60/GSF), will yield a lower TCO. Even though this building has been upgraded considerably for safety and security, the TCO still decreases from $103.40 to $102.70/GSF. Not only is the CapEx investment recovered, but overall life cycle costs are reduced while at the same time the building is being made more resilient to withstand multiple natural (safety) and man-made (security) threats including chemical attack protection.



Metric Results	Baseline		Benchmark (w/Energy)		Benchmark (w/Energy + CBR)	
	Building	Envelope	Building	Envelope	Building	Envelope
Energy (KBtu/SF)	57 to 69	14 to 17	54 to 65	11 to 12	54 to 65	11 to 12
Carbon (CO2e/SF)	30 to 37	7 to 9	29 to 34	6 to 6	29 to 34	6 to 6

Figure 4-9: Energy Performance Dashboard

Energy Performance

The Energy (CapEx) Improvement Cost graph shows the estimated investment (CapEx) and ROI for the building enclosure for each of the applicable energy-related sub-attributes. Results are shown in a range with the most probable value from within the range for the cost of improvements at the specified demand and performance levels identified. A summary for the whole-building, as well as that portion attributable to the enclosure (estimated pending a more complete analysis of whole building energy consumption in a future phase), for the energy consumption (KBtu/SF) and environmental footprint in the form of carbon equivalent (CO_2e/SF) for the baseline is included. A value for the benchmark, with Energy but without CBR improvements (if CBR protection was selected) is provided also. The benchmark with both energy and CBR improvements are also displayed on this dashboard.

The Energy Consumption graph shows the enclosure attributable energy (KBtu/SF) consumption both without CBR and then with CBR (if CBR protection was selected in the scenario).

Interpretation of Energy Performance Results

In the Energy Performance Dashboard example, the Baseline Energy Consumption is 51 to 63 Kbtu/SF/Year for the whole building, which includes 14 to 17 Kbtu/SF/Year attributable to the climate demands upon the building enclosure. Based on the user having selected an enhanced performance (P++) benchmark, the OPR Tool has produced the following outcomes:

1. An Energy consumption reduction of between 19% and 29% of the enclosure load from 14 to 17 Kbtu/SF down to 52 to 12 Kbtu/SF.
2. A total investment in energy improvements to the building of $3.30/GSF (predicted within a range from $2.50 to $4.50) with a Return on Investment of between 4% and 7%.
3. This improvement will be achieved through four categories of solutions as follows:
    a. Thermal Transfer related measures costing between $2.30/SF and $4.10/SF and achieving an ROI of between 3% and 5%.
    b. Air Infiltration related measures costing up to $0.20/SF and achieving an ROI of 18% to 33%.
    c. Daylighting controls measures costing up to $.30/SF and achieving an ROI of between 13% and 23%.
    d. Natural Ventilation and Solar PV are not necessary to achieve the targeted performance benchmark..

One reason the energy reduction and ROI are relatively low is because they are computed from a baseline of ASHRAE 90.1 2004, which already inherently is an improvement compared to the vast majority of the existing building stock. Were a lower baseline used, the relative improvements would be greater.

This example does not include CBR, which when included causes a significant adverse impact on energy consumption from operation of the HVAC system. Also note that the Benchmark Energy consumption attributable to the enclosure is less than zero. This is because the daylighting benefit is accruing to the envelope, and is greater than the sum of the other enclosure consumption values.

The environmental footprint of this scenario is an estimate of the carbon generated by the energy consumed to operate the building, as well as the enclosure portion only, based on the anticipated fuel mix at the building location. The values do not include embodied energy. How this value was established is discussed further in the Mechanical section of chapter 5.

Facility Resilience

The qualitative and quantitative outcomes for each of the Safety sub-attributes (seismic, flood, wind and fire) and Security (blast, ballistic and CBR) are presented comparably. For each sub-attribute, the range of relative Risk, Resilience and Continuity of Operations is shown graphically with colors: green representing low risk or high resilience, yellow for caution for both risk and resilience, and red for high-risk or low-resilience outcomes. Cost ranges and critical demand conditions are reported as well. CapEx is presented as $/SF to upgrade to the targeted level of performance. Exposure represents the cost in $/SF on the same basis that is anticipated to be incurred, based on the Input values for the baseline and scenario conditions over the specified Use Period.

The qualitative and quantitative outcomes for each of the Safety sub-attributes and Security are presented comparably. The range of relative Risk, Resilience and Continuity of Operations is shown graphically.

Interpretation of Safety and Security Performance Results

Interpreting the charts and graphs on this dashboard has already been covered above and applies equally here. This dashboard allows for evaluation of all of the safety and security performance investments side by side to illustrate where adjustments might be warranted to balance investment and anticipated return with overall objectives.

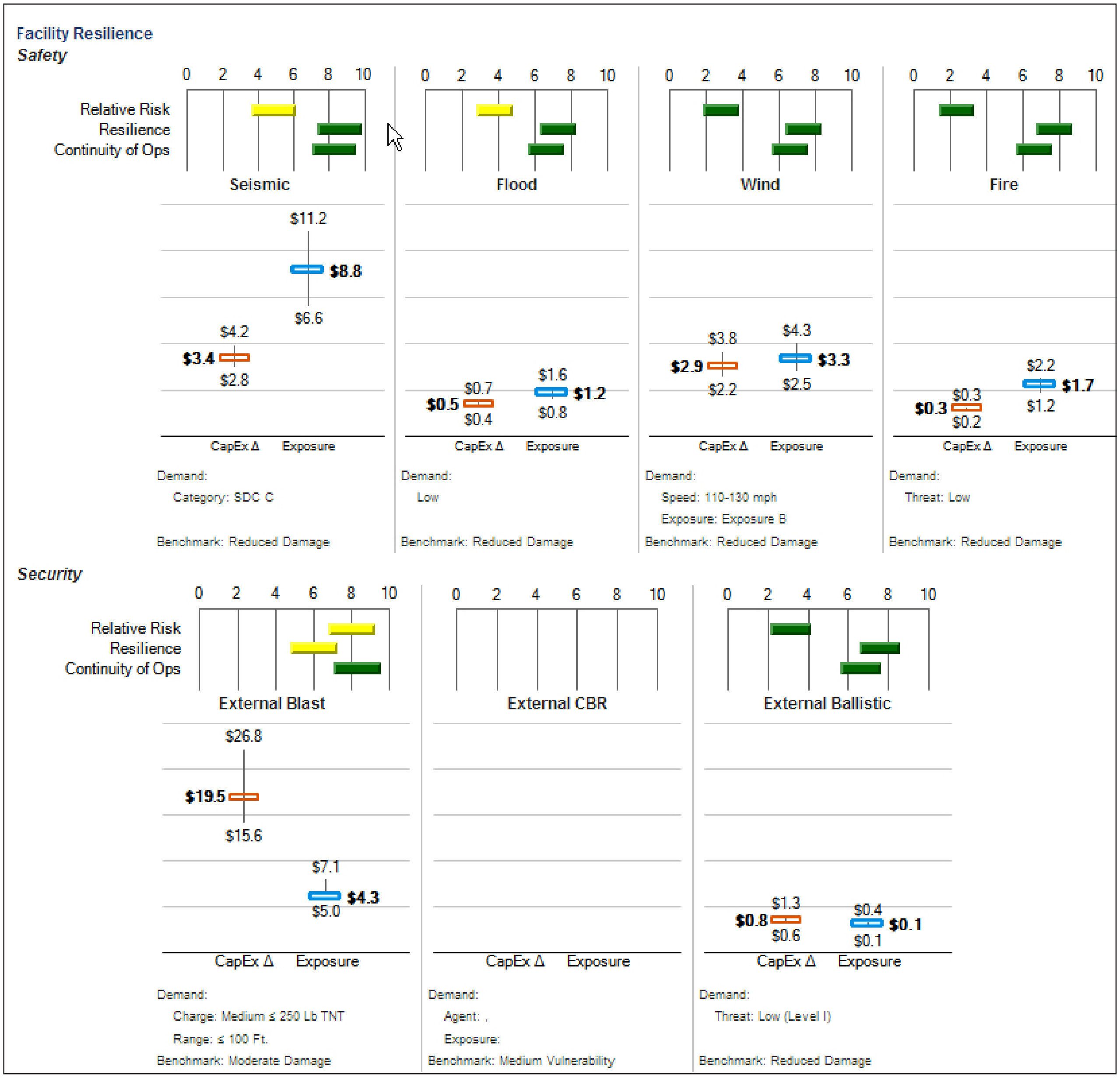
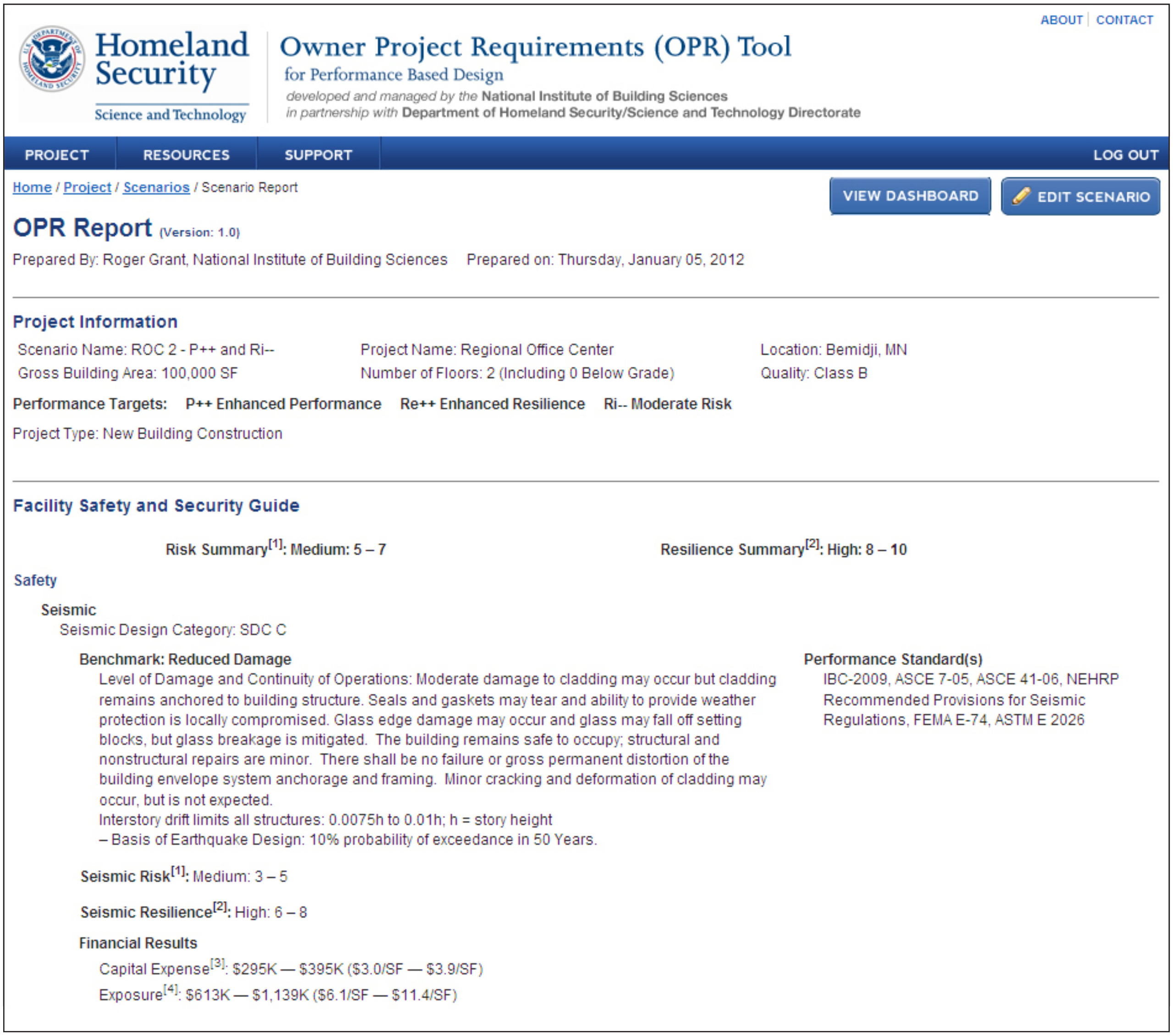


Figure 4-10: Safety and Security Performance Dashboard



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Homeland Security
Science and Technology

Owner Project Requirements (OPR) Tool
for Performance Based Design
developed and managed by the National Institute of Building Sciences
in partnership with Department of Homeland Security/Science and Technology Directorate

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VIEW DASHBOARD EDIT SCENARIO

OPR Report (Version: 1.0)

Prepared By: Roger Grant, National Institute of Building Sciences Prepared on: Thursday, January 05, 2012

Project Information

Scenario Name: ROC 2 - P++ and Ri-- Project Name: Regional Office Center Location: Bemidji, MN
Gross Building Area: 100,000 SF Number of Floors: 2 (Including 0 Below Grade) Quality: Class B

Performance Targets: P++ Enhanced Performance Re++ Enhanced Resilience Ri-- Moderate Risk

Project Type: New Building Construction

Facility Safety and Security Guide

Risk Summary[1]: Medium: 5 – 7 Resilience Summary[2]: High: 8 – 10

Safety

Seismic
Seismic Design Category: SDC C

Benchmark: Reduced Damage
Level of Damage and Continuity of Operations: Moderate damage to cladding may occur but cladding remains anchored to building structure. Seals and gaskets may tear and ability to provide weather protection is locally compromised. Glass edge damage may occur and glass may fall off setting blocks, but glass breakage is mitigated. The building remains safe to occupy; structural and nonstructural repairs are minor. There shall be no failure or gross permanent distortion of the building envelope system anchorage and framing. Minor cracking and deformation of cladding may occur, but is not expected.
Interstory drift limits all structures: 0.0075h to 0.01h; h = story height
– Basis of Earthquake Design: 10% probability of exceedance in 50 Years.

Performance Standard(s)
IBC-2009, ASCE 7-05, ASCE 41-06, NEHRP Recommended Provisions for Seismic Regulations, FEMA E-74, ASTM E 2026

Seismic Risk[1]: Medium: 3 – 5

Seismic Resilience[2]: High: 6 – 8

Financial Results
Capital Expense[3]: $295K — $395K ($3.0/SF — $3.9/SF)
Exposure[4]: $613K — $1,139K ($6.1/SF — $11.4/SF)

Figure 4-11: Project Performance Report - Excerpt

Owner Performance Report

For each scenario, the OPR Tool generates a tabular Project Requirements Report (a portion of which is shown above) that captures all of the essential user inputs and selections, resulting demands, descriptions of the attendant performance outcomes and the standards they are based on for each sub-attribute. Cost ranges for the Capital Expense, the Operating Expense and Re-Capitalization associated with durability are identified for each sub-attribute. The Exposure for each of the Safety and Security sub-attributes is also included with reports for the Operating Cost and Consequence (Recovery) cost associated with the occurrence of an event. At the end of the Project Requirements Report, the ranges of values for each cost category and the Total Cost of Ownership (excluding Re-Capitalization associated with a safety or security event) for the proposed enclosure solution are summarized.

It is important to note that these costs are highly variable.

It is important to note that these costs are highly variable. Ranges are identified, within which the actual value for a project might be anticipated to fall. **The values reported are not intended to be used as a preliminary project budget but are relative values to assist the owner in establishing performance targets.** A conceptual cost estimate should be performed to validate the numbers and identify a budget for the project.

The values reported are not intended to be used as a preliminary project budget but are relative values to assist the owner in establishing performance targets.

The Project Requirements Report documents the owner's performance requirements for the proposed project and could be provided to the design team to guide them in preparing a conceptual design to meet the performance based objectives established for the project.

4.2.3. Scenario Comparisons

The OPR Tool can create up to four "what if" or trial scenarios. One or all of these scenarios can be compared side-by-side. By creating different scenarios of the same project, the user can evaluate several alternative schemes for the project and compare them in a consistent way to select the best combination of performance and cost based on evaluating multiple scenarios. At any time, scenarios can be modified and compared again to optimize the solution.

The single scenario dashboards for each of the attribute categories described above reports the Mean, Low and High range values. The Scenario Comparison Dashboard compares only the mean values for any selected scenario. Comparison dashboards for Summary, Facility Operations and Facility Resilience can be selected from the View Dashboard Reports list. Shown below are example Scenario Comparison for Summary, Facility Operations and Facility Resilience with interpretation of results for each.

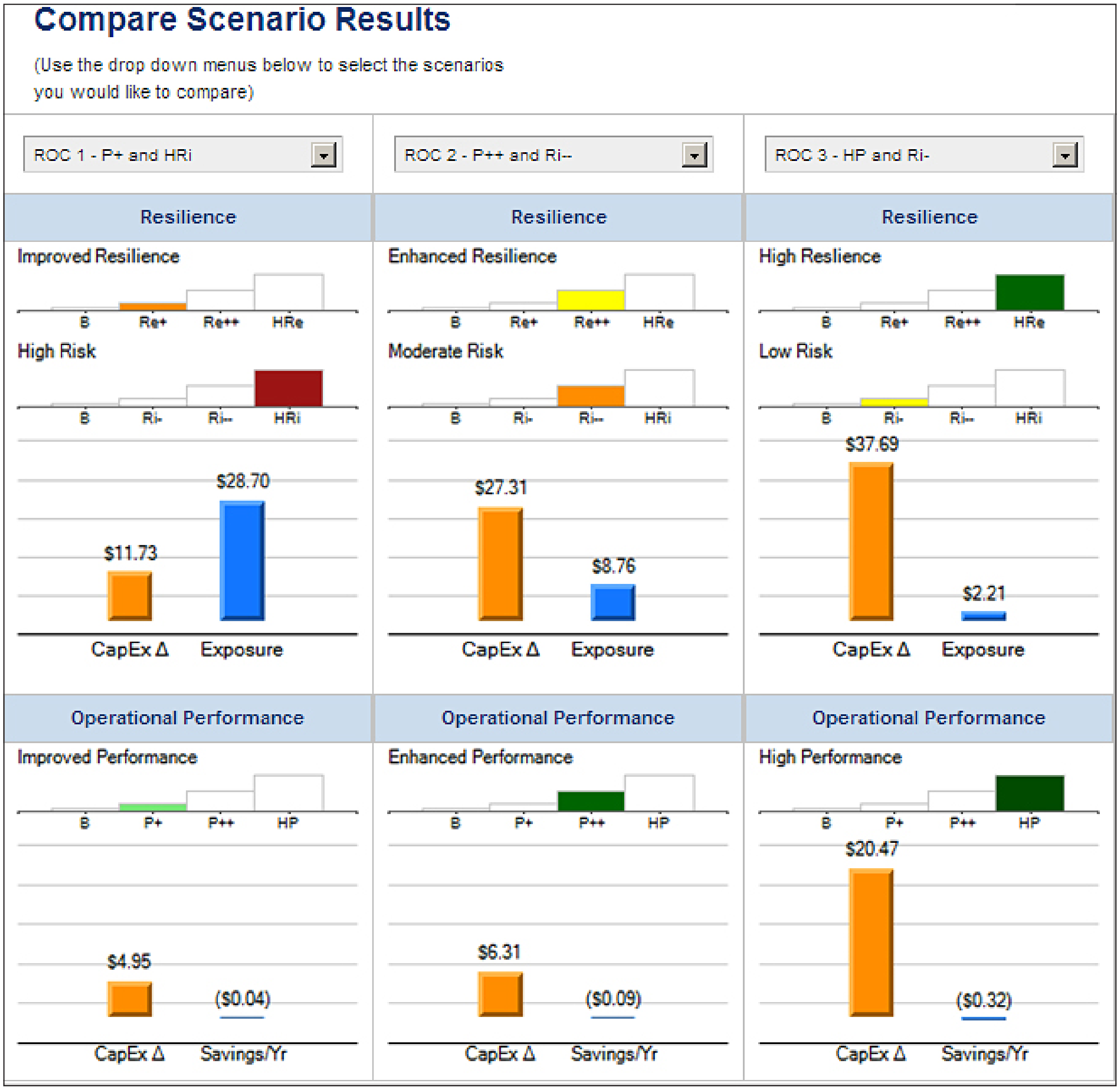

Figure 4-12: Scenario Comparison - Summary

Interpretation of Scenario Comparison Results - Summary

The results shown on the Summary comparison have been explained previously. Seeing them in comparison illustrates the relative cost and resultant return for each alternative. For this example, the relative cost to obtain High Performance is significant. Depending on the project objectives, it might be warranted to further evaluate all the choices made for the Improved and Enhanced scenarios. The Facility Operations and Facility Resilience dashboard views that follow assist in that evaluation.

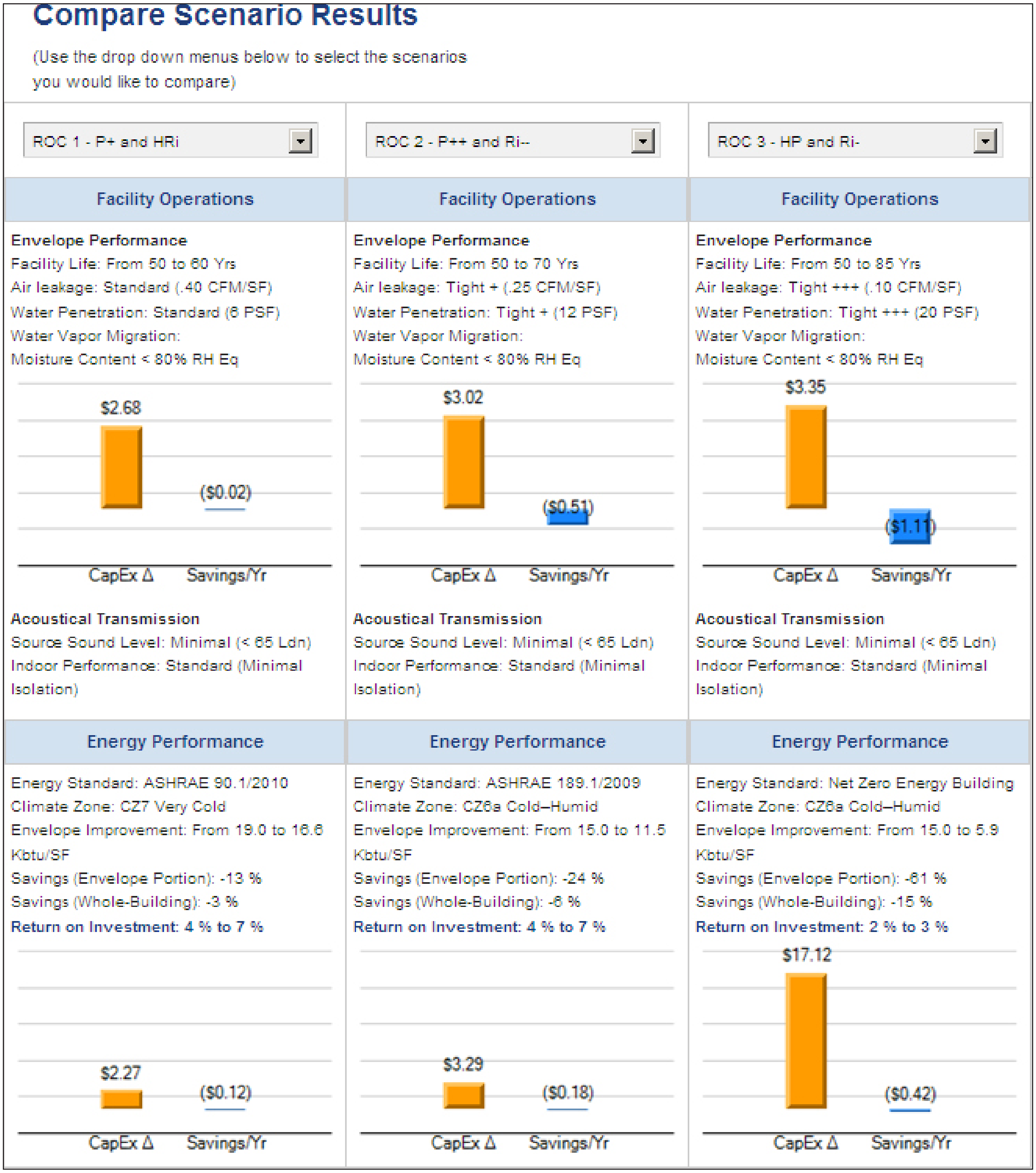

Figure 4-13: Scenario Comparison - Facility Operations

Interpretation of Scenario Comparison Results - Facility Operations:

1. **Facility Operations:** In this example, the enclosure (envelope) performance for durability (facility improvement) is evaluated. Acoustical transmission is held constant in each scenario. The baseline facility service life is 50 years. These three Scenarios go from P+ (60 years) to P++ (70 years) to HP (85 years) at capital expense increases of \$2.68/SF to \$3.02/SF to \$3.35/SF respectively. Based on the net present value of spreading the capital expense over more years of service life, this yields a total net savings of \$0.02/SF, \$0.51/SF and \$1.11/SF. The relatively small increase in investment can yield a significant increase in service life, assuming that appropriate measures are taken during construction to control installation quality. For more discussion of this point, see the Architectural section of Chapter 5.

2. **Energy Performance:** The three Scenarios step up the investments to reduce energy consumption from Improved P+ (\$2.27/GSF) to P++ (\$3.29/GSF) to HP (\$17.12/GSF) which yields annual energy savings of \$0.12/GSF to \$0.18/GSF to \$0.42/GSF respectively. The Return on Investment (ROI) range results are 4% to 7% for both the Improved (P+) and Enhanced (P++) Performance benchmarks indicating that the differences in performance are not great enough to yield an increase in ROI. To achieve High Performance (HP) requires adding a solar (PV) solution, which brings down the overall ROI range to 2% to 3% based on the added cost of the solar installation. Further evaluation of scenarios with different energy cost assumptions may be warranted and could impact the ROI calculations.

To achieve High Performance (HP) requires adding a solar (PV) solution.

Figure 4-14: Scenario Comparison – Facility Resilience

Interpretation of Scenario Comparison Results - Facility Resilience:

1. **Security:** From an investment vs. exposure perspective, Scenario 1 yields the best balance of capital expense investment ($9.51/SF) to exposure (operational costs plus recovery cost) of $8.83/SF. Scenarios 2 and 3 would require substantial capital expense investments relative to the exposure costs that would be bought down. As a result, these Scenarios are not economically justified unless Risk reduction is warranted for other reasons.
2. **Safety:** Scenario 1 yields a relatively small capital expense increase of $2.58/SF, but creates a high exposure (operational costs plus recovery cost) of $28.70/SF. Scenario 2 is the most balanced option with capital expense to exposure of $6.99/SF to $8.76/SF. For a relatively small incremental additional capital expense investment to $9.00/SF, the resulting exposure in Scenario 3 is significantly reduced to $2.21/SF which may make this the most attractive alternative depending on investment vs. risk objectives for the project.

4.2.4 Applying the OPR Tool to Plan a Project

Using the OPR Tool to evaluate a proposed project as described above lets the owner capture general project information and performance objectives at a very early stage in the planning process. The Scenario Comparison feature allows for the development of up to four different scenarios that can be compared side by side so that the consequences of different choices can be evaluated. This is especially important early in the planning cycle before any design decisions have been made and is a powerful feature of the tool. The Interpretation of Results sections above provide guidance on how to read the dashboard results when evaluating scenarios.

The range of attributes covered by the OPR Tool make it possible for an owner to evaluate all of the critical aspects of performance at one time. The result is the ability to see side-by-side the cost and benefits of enhancing or downplaying all aspects of a proposed enclosure scenario for a project. In this way, cost-benefit based decisions about whether to enhance security can be made considering the corresponding impact on energy conservation for example. As part of the analysis, the relative cost to provide the targeted level of security protection can be evaluated alongside the potential risk of a security threat. This same kind of evaluation can be performed for all of the project's attributes.

Using the OPR Tool to evaluate a proposed project lets the owner capture general project information and performance objectives at a very early stage in the planning process.

When sufficient scenarios have been explored, a Performance Report for the selected scenario can be generated. This report can be used as guidance for the design team to give them quantifiable targets to strive for and to report against. The Performance Report establishes the Owner Performance Requirements in terms of design performance goals and a broad range of potential costs to achieve those goals. This equates to the establishment of Owner Project Requirements, the first step identified by the building commissioning process as standardized in ASTM E.06.55.09 Standard Practice for Building Commissioning, for *"achieving, verifying, and documenting that the performance of facilities, systems, and assemblies meets defined objectives and criteria."* With these requirements firmly in place, a proven step towards achieving a successful project and integrating the owner and design teams early on is established.

The Performance Report establishes the Owner Performance Requirements in terms of design performance goals and a broad range of potential costs to achieve those goals.

5

Technical Analysis

The following sections review the analysis of performance levels for the four technical categories that encompass enclosure behavior: architectural, structural, fenestration and mechanical. These sections focus on building enclosure system performance in response to a range of demands. The investigations that the Project Team conducted to establish baseline and increasing performance targets for the OPR Model are detailed here.

5.1 Architectural Analysis

5.1.1 Introduction

The design and construction industry has increasingly been focusing on higher-performance building enclosures (envelopes), with the goals of maximizing the energy conserving features and durability of buildings and achieving the desired acoustic performance, while at the same time addressing safety and security concerns. As the industry heads down this pathway, it becomes imperative that the building enclosure be scrutinized for opportunities to reduce energy loss and gain through the enclosure, increase the durability of the building enclosure, and achieve appropriate

The design and construction industry has increasingly been focusing on higher-performance building enclosures, with the goals of maximizing the energy conserving features and durability of buildings and achieving the desired acoustic performance, while at the same time addressing safety and security concerns.

acoustic separation based on indoor function and outdoor noise. This entails minimizing heat transfer by conduction, convection and radiation; management of liquid water; achieving an air-tight enclosure; reducing the likelihood of condensation and bacterial growth; and the proper selection of assembly components for the desired acoustical performance. This section of the report will describe how the team defined and quantified he performance of these sub-attributes to contribute to the OPR model.

5.1.2 High Performance Criteria

5.1.2.1 Attributes and Sub-attributes

The team's architectural analysis covered the EISA attributes of energy conservation, environment and durability as related to the building enclosure. For energy conservation, identifying the energy use attributable to the building enclosure at varying levels of demand and performance was the goal of the analysis. For environment, the architectural analysis was confined to acoustic transmission/isolation to identify how the enclosure system responded to sound levels. For durability, the key goal was to establish resistance to water penetration and to wetting due to condensation and service life and then analyze the impact on the project.

Energy Conservation Sub-attributes

One of the key measures of high performance is the energy a building consumes. To assess this, the team analyzed the energy consumption of non-renewable resources and thermal transfer through the building enclosure. When analyzing heat transfer, air-tightness is a critical performance criteria. For whole building enclosures and for assemblies, air barrier continuity on all six sides is key to air-tightness control. A continuous air barrier in the enclosure is the way to ensure continued air-tightness of the opaque assemblies and their connections to fenestration. Achieving fenestration air-tightness depends upon the metal joinery gaskets and sealants.

One of the key measures of high performance is the energy a building consumes.

Environmental Sub-attributes

Acoustics are an important component in the comfort and productivity of a building's occupants. The acoustical performance of the exterior façade design is the primary factor for how noise from the building exterior is mitigated from adversely impacting the occupants. This is an increasingly critical design component for buildings sited near urban areas or transportation corridors.

Durability Sub-attributes

The sub-attribute of water penetration is visible water penetration or accumulation.

Water Vapor Control is important to avoid mold and microbial growth, as well as corrosion, rot and decay.

Water Vapor Control is important to avoid mold and microbial growth, as well as corrosion, rot and decay. The metric is the increase in % relative humidity or equivalent moisture content for the enclosure materials for a given length of time in days, at a given temperature. Service life is a function of the quality of the systems employed in a project and level of performance targeted. Quality is decided on by an owner, based the goals for a project. For this measurement, predictions on corresponding service life of the building and specific building system were made based on quality level and performance benchmarks, though cost also usually plays into the selection by the owner.

5.1.2.2 Demands

For each of the attributes/sub-attributes evaluated, there is a corresponding demand placed on it by the project and the goals for the project. Key considerations for energy conservation, durability and environmental demands are:

Energy Conservation and Durability

The Climate Zone in which the building is located determines the variable demand for energy and durability related attributes and sub-attributes.

The Climate Zone in which the building is located determines the variable demand for energy and durability related attributes and sub-attributes. When analyzing whole building energy consumption, latent loads and wet vs. dry climates are a significant influence. The team selected four climate zone groupings:

1. CZ 1 & 2– Hot to Very Hot
2. CZ 3 & 4 – Warm to Mixed
3. CZ 5 & 6 – Cool to Cold
4. CZ 7 & 8– Cold to Very Cold

For the modeling of enclosure insulation levels and fenestration performance detailed in the Fenestration section that follows, the analysis uses only three climate zone categories since the variability decreases for the specific systems and the three zones better fit the performance of the systems. Results from the three zones used in the system performance modeling – CZ 1, 2&3; CZ 4. 5 & 6 and CZ 7 &8 – are mapped to the four zones used in the OPR model in the OPR database.

Demands for water penetration can be acute yet vary tremendously in different climate zones. For example, climate zones A and C are wet and rainy, and climate zone B is dry but gets flash flood rains. For water vapor control, climate zone weather combinations of solar radiation, temperature, relative humidity, rain and cloud cover all influence performance. The selection of enclosure materials and their layering and material properties (including permeance), determine successful performance. In addition to the climate zone variation, the quality of the building construction will also play a determinant in service life.

In the model, air leakage/tightness has a constant demand, irrespective of climate zone and quality factors affecting other enclosure architectural attributes.

Environmental

Exterior noise exposure at the facility site consists of the variable demand placed on the building that impacts acoustic isolation performance. The acoustical impacts will vary dramatically based on the noise levels that are experienced at the facility site. The metric for quantifying this impact is the annual day-night average sound level (LDN).

Exterior noise exposure at the facility site consists of the variable demand placed on the building that impacts acoustic isolation performance.

To determine the noise exposure at a site, the recommended practice is for an owner to consult with the operator of the nearby noise source to ascertain whether a quantitative understanding of the noise emissions from the source is available. For example, most airports with military or commercial aircraft operations produce noise contours of the surrounding areas showing the estimated LDN levels from the anticipated aircraft operations. Alternatively, for highway and rail noise, the applicable transportation department may be able to provide estimated LDN based on typical anticipated traffic volume, vehicular mix and speed. These quantitative sources of noise emissions can be used for the basis of the noise exposure to the site.

In a situation where the operators are not able to provide such quantitative noise emissions information, an estimate of a site's noise level exposure can be obtained by using the U.S. Department of Housing and Urban Development (HUD) Noise Guidebook. Chapter 5 of the Noise Guidebook presents the methodologies for estimating noise impacts from aircraft, rail and highway operations. Performing these methodologies may require the assistance of an engineering consultant.

In the absence of noise emission data from either of the two approaches proposed above, a simpler, but less accurate, approach may be used for very preliminary estimates of a site's noise exposure. For this approach, the range of facility potential noise levels could be initially identified by the following categories:

- **Minimal** – Characterized as being distant from any significant transportation noise sources and having a LDN less than 65 dB.
- **Moderate** – Characterized as being near to one or more transportation noise sources and having a LDN higher than 65 dB, but lower than 70 dB.
- **Significant** – Characterized as being close to one or more significant transportation noise sources and having a LDN higher than 70 dB, but lower than 75 dB.
- **Severe** – Characterized as being very close to transportation noise sources and having a LDN higher than 70 dB, but lower than 75 dB.

Table5-1: Exterior Noise Levels

Impact Description	Distance (ft) from Transportation Noise Source			Estimated Noise Exposure LDN (dB)
	Aircraft Flight Path	Railway	Highway	
Minimal	>7,000	>1,500	>1000	<65
Moderate	3,500 to 7,000	500 to 1,500	250 to 1,000	65 to <70
Significant	1,800 to 3,500	125 to 500	60 to 250	70 to 75
Severe	<1,800	<125	<60	>75

Regardless of the methodology, the acoustical impact to the facility, based on the different exterior noise exposure, is an important parameter to use for the determining the outcome. These site-related impacts should be coordinated with the interior sound level benchmarks, which are described below. It is assumed that the acoustic issue relates only to airborne noise (above grade). Structure-borne vibration (typically from railway and subway systems) is not considered in this system. Instead, such acoustical demands would be considered factors relating to the operational performance for the facility.

5.1.2.3 Baselines and Benchmarks

Energy Conservation

The Project Team selected ASHRAE 90.1–2004 as the baseline for whole building energy use , since that is the baseline for comparing advances in energy conservation to meet the requirements of the Energy Policy Act of 2005 (EPACT) and EISA 2007. Following from that choice, the team selected ASHRAE 90.1 – 2010 as the P+ level with an improvement in energy efficiency of approximately 30%. For the P++ level the team targeted 50% better than ASHRAE 90.1 2004 for whole buildings, and corresponding to that target level, ASHRAE 189.1 – 2009 for enclosure assemblies, since the enclosure requirements are more stringent than in 90.1–2010. The highest level that is thought to be achievable is the level at which an investment in renewable energy sources could be made to make up for energy used and provide Net Zero Energy Buildings (NZEBs). For the enclosure, the level corresponds to the requirements of the German Passive House standard.For whole building energy, the level equates to requirements of ASHRAE 90.1 2004 – 60%. For roof, wall and floor insulation levels and for fenestration performance levels, the same baselines and benchmarks described above hold, although the energy saved between levels is not the same percentage as for whole buildings.

> Air tightness is an important component of achieving energy performance and durability in buildings.

For air tightness, three levels of performance have been identified: standard, tight and very tight, corresponding to ASTM standards for the enclosure and whole building. The ASTM standards are as follows:

- For air barrier materials: ASTM E 2178
- For building assemblies: ASTM E 2357, ASTM E 273, ASTM E 783, ASTM E1186,
- For fenestration: ASTM E 283, ASTM E 783, ASTM E1186.
- For whole buildings: ASTM E779
- For diagnostics, ASTM C 1060 and ASTME E1186
- The U.S. Army Corps of Engineers (USACE) air-tightness test protocol modifies ASTM E779 to include testing big buildings.

Air tightness is an important component of achieving energy performance and durability in buildings.

Environment – Acoustic Isolation

The acoustical objectives for the occupants are based on the interior sound levels that are appropriate for program uses of the spaces. The range of interior sound levels is identified by the following categories:

> The acoustical objectives for the occupants are based on the interior sound levels that are appropriate for program uses of the spaces.

- **Baseline –** characterized as being a moderate sound level, consistent with typical HVAC design for general commercial office spaces and having a Noise Criteria (NC) of NC-35 or higher;
- **Standard (P+) –** characterized as being the sound level objective for a typical private office, consistent with typical HVAC design of private offices and having a Noise Criteria (NC) of NC-30 to NC-35;
- **Quiet (P++) –** characterized as being the sound level objective for a conference, meeting, or training room, consistent with a low noise HVAC design and having a Noise Criteria (NC) of NC-25 to NC-30;
- **Very quiet (HP) –** characterized as being the sound level objective for a video conference room or facility with audio recording, consistent with a very low noise HVAC design and having a Noise Criteria (NC) of less than NC-25;

Based on the exterior noise exposure listed in the Demands and these interior sound level criteria for benchmarks, the acoustical performance of the façade should be designed to provide sufficient mitigation to achieve suitable acoustical conditions for the occupied spaces.

Durability

- **Water Penetration:** The baseline and benchmarks selected are baseline, standard, tight and very tight resistance to water penetration for opaque walls and fenestration as measured by ASTM E 331 static water test in the lab, ASTM E1105 in the field, AAMA 501.1 for dynamic testing and AAMA 501.2 for diagnostic work.
- **Water Vapor Control:** Like Water Penetration, the baseline and benchmarks selected are baseline, standard, tight and very tight resistance. Since no increase in moisture content above a certain threshold for a given time at a certain temperature is allowed in opaque assemblies, according to ASHRAE Standard 160, the benchmark is Pass/Fail.
- **Service Life:** Service life levels of baseline, improved, enhanced and high performance are used. No citable standards are available except in the case of Fenestration where the Moisture Resistance Index can be used to evaluate fenestration longevity. Other benchmark levels have been established based on practice.

5.1.2.4 Metrics and Outcomes

The metrics and resulting performance outcomes documented in this section are summarized in Appendix A for each sub-attribute.

Energy Conservation

The metric for whole building energy use selected is "whole building Energy analysis" following Appendix G of ASHRAE 90.1. It is measured in "kBTU /GSF/year". Values for building energy use employed in the project are derived from studies performed by Pacific Northwest National Labs in support of ASHRAE 90.1 and other ASHRAE committees that simulate performance for a mid-sized office building. The whole building values have been converted to the percentage attributable to the enclosure through further modeling on the PNNL data performed as part of the Fenestration analysis to isolate the effects of enclosure from other energy conservation measures in the broader ASHRAE guidelines. The Mechanical analysis also isolated the percentage attributable to the enclosure by segregating effects of other components of energy use from the PNNL whole building values. Both approaches are described in detail in those sections of this chapter. The aggregation of these values is used in the OPR Tool to establish performance targets in the Performance Requirements report and as part of the cost prediction process for calculating savings in energy costs from increasing performance targets.

For roof, wall and floor assemblies, the metric would be the result of a guarded hot box ASTM C1363 test or simulation using Finite Element Analysis with software such as THERM with the results expressed as a "U-Factor" measured in Btu/ft^2·°F ·hr. Fenestration performance is measured in accordance with NFRC 100, AAMA 507 or the NFRC's CMA Software Tool and the measurement unit is the U-Factor in Btu/ft^2·°F ·hr. A secondary metric for fenestration is the solar heat gain coefficient or SHGC, a number between 0 and 1, measured in accordance with NFRC 200, AAMA 507 or the NFRC's CMA Software Tool. A third metric for fenestration, useful for day lighting studies is the Visible Transmittance of light through the fenestration, or VT, also measured by NFRC 200 and the CMA tool. These metrics are used in the analysis of Energy use by both the Mechanical and Fenestration committees and are discussed further in those sections.

The metric for air tightness is cubic feet per minute per square foot of surface area (cfm/ft^2) at a specified water gauge (w.g.). The baseline or low performance for whole building air tightness is 0.4 cfm/ft^2 @ 0.3" w.g. of building enclosure (six sides including slab on grade and below grade walls). This benchmark has been included by several sources, including ASHRAE 189.1, GSA's P-100 – 2010, USAF and IBC 2012 (IBC 2012 now mandates a continuous air barrier requirement in climate zones 4 and higher and ASHRAE 2010 essentially mandates continuous air barriers for all climate zones) with a certain level of whole building air-tightness as an optional compliance pathway (0.4 cfm/ft^2 @ 0.3” w.g or 75 Pa). The medium level is 0.25 cfm/ft2 @ 0.3” w.g, and is the level selected by USACE and NAVFAC, although USACE is headed towards 0.15 cfm/ft@ 0.3” w.g. The tightest target level is 0.1 cfm/ft^2 @ 0.3” w.g. and USACE experience shows us that this level is achievable, and should be considered in buildings sensitive to external chemical biological or radiological attacks and that are using air pressurization as a method of mitigating the problem.

Environment – Acoustic Transmission

Based on the exterior noise exposure listed in the Demands and these interior sound level criteria for benchmarks, the acoustical performance of the façade should be designed to provide sufficient mitigation to achieve suitable acoustical conditions for the occupied spaces.

The Outdoor-Indoor Transmission Class (OITC) is used to quantify the acoustical performance of façade constructions. This metric is defined in ASTM E1332–10A (most recent revision of the standard) for use to determine from test data gathered in laboratory (ASTM E90) or field conditions (ASTM E966).

Table 5-2: Exterior Sound Levels

Interior Sound Level Goal	Exterior Sound Level at the Site (LDN)			
	< 65 dB	65 dB – 70 dB	70 dB – 75 dB	> 75 dB
Baseline (NC-35 or higher)	OITCc 30	OITCc 30	OITCc 30	OITCc 35
Standard (NC-30 to NC-35) (P+)	OITCc 30	OITCc 30	OITCc 35	OITCc 40
Quiet (NC-25 to NC-30)(P++)	OITCc 30	OITCc 35	OITCc 40	OITCc 45
Very Quiet (NC-25 or lower) (HP)	OITCc 35	OITCc 40	OITCc 45	OITCc 50

OITCc is defined as the composite OITC performance of multiple items within a façade, such as an opaque wall construction versus the windows. This is determined by calculating the proportional areas and the associated OITC performance of each different construction to account for how each contributes to the OITC performance of the overall system.

Durability

The Water Penetration measurement standard selected for opaque walls, doors and fenestration is ASTM E 331 static water test in the lab, ASTM E1105 in the field, AAMA 501.1 dynamic testing and AAMA 501.2 for diagnostic work. The metric is “no leakage at 20% of design wind pressure or at a specified pounds/square foot (psf) for the performance level desired, whichever is more”. Pressure values are identified in the Attribute Summary Performance Matrix for Facility Operations in Appendix A. For walls below grade above the water table an AAMA 501.2 hose test can be useful. For walls below grade below the water table, the metric would be to stop dewatering and allow the water table to resume its natural level. The metric would be “no leakage”, although some leakage may be tolerated as a baseline for low performance in unoccupied space. Certainly water in buildings is not desirable under any circumstances due to microbial growth and indoor air quality concerns, loss of durability and effect on service life. For capillary water rise in building materials, moisture meters can be used and a maximum moisture content selected that may be below 20% Wood Moisture Content equivalent. For roofs, plaza deck waterproofing and vegetated roofs, Electric Field Vector Mapping and high voltage testing are the state of the art measurements. Permanent leak detection systems can be considered also. For slabs with floor finishes, ASTM F2170 is the best test. Flooring manufacturers will specify the maximum moisture allowable as emissions from slabs by specifying the % Relative humidity as a result of the probe testing.

For Water Vapor Control, Transient Hygrothermal modeling pass/fail thresholds for moisture accumulation according to ASHRAE Standard 160 are:

- 30-day running average surface RH < 80% when the 30-day running average surface temperature is between 5°C (41°F) and 40°C (104°F), and,
- 7-day running average surface RH < 98% when the 7-day running average surface temperature is between 5°C (41°F) and 40°C (104°F), and,
- 24-hour running average surface RH < 100% when the 24-hour running average surface temperature is between 5°C (41°F) and 40°C (104°F).

As noted above, since no increase in moisture content above a certain threshold for a given time at a certain temperature is allowed in opaque assemblies, benchmark and baseline performance is either Pass or Fail. Analysis using a Transient Hygrothermal model, such as WUFI is recommended, although its limitations should be recognized, the most important of which is condensation due to air-flow, or air leaks.

The average service life of a single ply membrane in the US is 12 years. It was rounded off to 10 years and different systems were compared to the 10 year number. For fenestration, the service life of the insulating glass unit is dependent on the rate of diffusion of moisture into the unit and the amount of dessicant available to absorb that moisture, measured by the Moisture Resistance Index or MRI. Often EPDM gaskets will require replacing in 10 to 15 years whereas silicone gaskets will last the life of the building. Often service life will depend on the finish applied and whether the finish is maintainable. Predicted service life values for roof, opaque walls, fenestration and whole buildings by performance level are identified in the Attribute Performance Summary – Facility Operations matrix in Appendix A.1.

5.1.3 Performance Evaluation

To assist in establishing the Performance levels identified in the OPR model, the performance of specific systems was evaluated and used to establish the general performance outcomes identified in the previous section. Specific systems and their anticipated performance as well as the range of costs for providing these systems to a proposed building are evaluated here. These values populate the Technical and Financial Report generated by the OPR Tool for any scenario developed drawing from the – HPBDE Attribute-Metric-Performance Summary – Facility Operations matrix, AppendixA.1.

5.1.4 Systems for Meeting Demands/Resisting Threats

Four major functional systems that comprise the building enclosure– Basement Walls, Opaque Walls, Fenestration and Roofing (including Roof Structure) – were evaluated to estimate the requirements to meet the demands and performance levels in the OPR model. The evaluation of systems was to identify the range of possible options for meeting performance goals so that costs for upgrades from baseline could be identified within a prescribed range. In addition, wall construction for acoustic isolation was evaluated. Some considerations taken into account when evaluating systems performance are identified here.

1. **Basement walls –** Waterproofing system choices vary depending on whether the space is fully occupied; the level of water-table and type of soil; and the performance level the owner expects.
2. **Opaque walls –** Opaque assemblies can be designed to meet all of the performance requirements of the demands/threats anticipated. This entails good design for the climate zone and energy efficiency levels needed. Cladding type determines service life, whether EIFS, masonry and stone veneer, or metal clad (both aluminum composite

metal (ACM) panel and sheet metals of different kinds). Precast concrete can be selected as a panelized system, either single slab, or composite double sandwich with insulation in the middle. Rain-screen systems include metal and stone claddings and terra-cotta.

3. **Fenestration –** Fenestration is currently the biggest hurdle to energy conservation. Although technology is available to provide high performance, the highest performing glazing is quadruple glazing with heat mirror foils and krypton gas fill, at a substantially increased cost. However with the kind of performance that triple and quad glazing delivers, perimeter heating systems can be eliminated in colder climates in buildings that have a 24/7 operating schedule. For buildings that operate on a partial schedule, it is more economical to shut down the air handling systems and maintain a hydronic heating capability. Frame strength versus energy performance is another hurdle; the most energy transmitted through fenestration systems is through the framing system. With blast resistance requirements, energy performance deteriorates further, since thermal breaks become a question.

4. **Roofing –** The major two categories of roofing are low slope or pitched roofing. There are several types of roofing available, from an inexpensive single-ply, to two-ply or three-ply modified bitumen. Protected membrane roofs and vegetated roofs extend the service life of membranes, since they are protected from UV degradation and are more stable from a temperature point of view. Pitched roof assemblies vary from a variety of selection of materials and assemblies that deliver different service life. These vary, from asphalt and slate shingle varieties, to painted or natural sheet metal types.

5. **Acoustical –** There are a variety of suitable constructions that could be used as examples for what will satisfy the acoustical metrics that are arrived at by the analysis of the demands and performance benchmarks. Below is a description of the different constructions that describe these possible outputs and that were evaluated for estimating the cost to upgrade to meet the specified level of noise isolation:

   - Opaque Wall Constructions
     - OITC 35 – Exterior thermal façade with interior finish wall
     - OITC 40 – Exterior thermal façade with interior finish wall
     - OITC 45 – Exterior thermal façade with structural stud support and a separately framed interior finish wall
     - OITC 50 – Exterior masonry (face brick) and thermal façade with stud structural support with a separately framed interior finish wall

- Window Constructions
  - OITC 30 – 1-inch thick insulating glazing (1/4 glass + 1/2-inch AS + 1/4 glass)
  - OITC 35 – 1 1/8-inch thick insulating glazing (1/4 glass + 1/2-inch AS + 3/8 laminated glass)
  - OITC 40 – 1-inch thick insulating glazing with interior 3/8-inch thick pane spaced at least 2 inches inside exterior glazing
  - OITC 45 – 1-inch thick insulating glazing with interior 3/8-inch thick pane spaced at least 6 inches inside of exterior glazing
- Roof Constructions
  - OITC 35 – Metal deck, thermal insulation, roof protection board, roof membrane and ACT ceiling below
  - OITC 40 – Composite metal deck with an average 4-inch concrete, thermal insulation, roof protection board, roof membrane and ACT ceiling below
  - OITC 45 – Composite metal deck with an average 4-inch concrete, thermal insulation, roof protection board, roof membrane and GWB ceiling below
  - OITC 50 – Composite metal deck with an average 4-inch concrete, thermal insulation, roof protection board, roof membrane and resiliently suspended double GWB ceiling below

It may be useful to note that the proportional area of the windows may need to be reduced if the requirement is to achieve the highest OITCC outcome.

It may be useful to note that the proportional area of the windows may need to be reduced if the requirement is to achieve the highest OITCC outcome (OITCC 50) given that windows do not achieve this high level. Alternatively, a space that is to achieve the Very Quiet level of interior sound may need to be located further within the facility, if the site is exposed to a Severe (LDN>75) noise level.

5.1.5 Performance for Sub-attributes

Performance levels for the architectural systems identified above are further documented in Appendix A.1 HPBDE Attribute-Metric-Performance Summary – Facility Operations which provides summary level performance information by sub-attribute.

5.1.6 Cost Impacts

Costs were estimated for construction of the systems identified above, with no upgrades for special demands or performances above code minimum for the three BOMA quality levels used for the project, to establish the baseline cost. Factors to adjust walls and fenestration to upgrade the systems to meet elevated demands and the benchmark performance levels were then evaluated to provide the cost increase factors needed to populate the OPR model. Some of the factors taken into account when evaluating the upgrade costs to meet the higher demand and performance benchmarks are identified here.

Energy Conservation

Thermal Transfer – The energy savings associated with the levels of insulation and fenestration recommended for Baseline, P+ and P++ have been proven to provide reasonable payback before inclusion in the ASHRAE Standards, ASHRAE 90.1 and 189.1. For the highest levels of performance, these investments would have to be evaluated based on building size, shape, orientation, internal loads and design through whole building energy analysis to be reliably verified. However, estimates based on experience were made. These are further validated by simulation using the Energy + model as further described in the Fenestration section that follows.

Air-tightness – Continuous air barrier joints and junctures must be included in the drawing details. Air-tightness targets must be included in the specifications, as well as requirements for whole building air-tightness testing. Added costs are those of peer reviews, added quality control during construction and the cost of the test.

Environment

Acoustic Isolation – The cost impacts of acoustical performance are strongly dependent on the outcomes. Many of the interior sound level goals for the baseline and improved performance standard are achieved when the facility is sited in areas where there is minimal or moderate exterior noise exposure without any additional cost.

Durability

Water Penetration – Waterproofing materials, drainage planes and flashings are fairly inexpensive, although high-end materials for long service life may be at a small premium. Proper design and quality control during installation would give assurances of high performance but would require additional costs through consultant oversight.

Water Vapor Management – The only added cost for assurances of proper water vapor management is the cost of hygrothermal analysis.

Service Life – Longer service life systems usually have a premium attached to their costs. The service life of a building assembly is limited by its least durable component.

5.1.7 Interactions

Interactions leading to an additional cost or potential benefit associated with design for fire-protection (insulation types), external ballistic (added steel layers or fenestration complexity), external CBR protection (air-tightness at the highest level) and daylighting (fenestration is more expensive than opaque assemblies) are likely and were included in the analysis of the architectural attributes and systems. Fenestration is likely to have premiums associated with seismic activity, in flood zones, and with higher project durability requirements. Roofing is likely to have premiums associated with higher design wind requirements.

Acoustical performance of the façade constructions has various potential interactions with other sub-attributes that can provide complementary benefits. The most beneficial interactions occur with ballistic protection, blast protection and thermal transfer.

Acoustical performance of the façade constructions has various potential interactions with other sub-attributes that can provide complementary benefits.

5.1.8 Validation and Verification of Results

Validation and verification of results can be considered on two levels – for the predictions of performance and corresponding estimates of cost to achieve that performance, and for the actual performance exhibited in the field. Discussion of prediction validation is covered in Chapter 7. Following are some considerations for validating and verifying that the performance levels resulting from the OPR analysis are actually achieved by the building.

- For energy, validation and verification of the results can be accomplished by metering/sub-metering and monitoring of building energy use vs. design predictions.
- Water penetration, water vapor management and air-tightness can be validated and verified if the building enclosure is commissioned, from design through construction. Many tests are available during construction, both in the lab and in the field; see Appendix A.1 for more information.

- There is little that can be done to validate service life, except to select systems based on service life track records, and making sure the building is commissioned to get the best possible design and installation.
- Acoustical validation can be accomplished by having a qualified acoustical consultant provide laboratory or field tests to demonstrate that individual components planned for the façade construction actually achieve the OITC ratings required to meet the OITCC performance of the outcomes. Such acoustical tests should be performed in accordance with ASTM E90 with the OITC results classified in accordance with ASTM E1332. Post-construction verification of the façade OITCC performance is possible in the field by performing acoustical testing in accordance with ASTM E966 and utilizing ASTM E1332 to classify the results. Such tests should be performed by a qualified acoustical consultant.

5.1.9 Conclusions and Recommendations

A list of specific conclusions and recommendations deriving from the architectural analysis are:

1. Designers must continue to optimize building enclosures and how they interact with other building energy consuming/conserving systems, in order to improve the performance of buildings. It will be inevitable to look at active façade systems integrated with Building Automation Systems, to maximize the free cooling that can be afforded by the thermal mass of the building and exterior shading using operable shades to minimize heat gain and glare. Conflicts with CBR protection no doubt will have to be evaluated.
2. Commissioning the building enclosure will likely benefit the outcome of water and water vapor management, as well as the air-tightness.
3. The extent of service life targeted is an owner's choice depending on their needs and goals and has related costs connected to the choices.
4. By experimenting with different demands and benchmarks using the OPR Tool, or by consulting the matrix in Appendix A.1, the anticipated performance may be evaluated and targeted for the façade of a facility.

5.1.10.References

Energy:

1. Guarded hot box ASTM C1363 *Standard Test Method for Thermal Performance of Building Materials and Envelope Assemblies by Means of a Hot Box Apparatus*

2. Simulation using Finite Element Analysis tools such as Therm.
3. Whole building energy analysis: Software tools such as Energy Plus, Trynsis, DOE 2- based software and other similar tools.
4. National Fenestration Rating Council: NFRC 100, 200, 300, 400, CMA Software Tool

Water Penetration:

1. ASTM E 331, S*tandard Test Method for Water Penetration of Exterior Windows, Skylights, Doors, and Curtain Walls by Uniform Static Air Pressure Difference*
2. ASTM E1105, *Standard Test Method for Field Determination of Water Penetration of Installed Exterior Windows, Skylights, Doors, and Curtain Walls, by Uniform or Cyclic Static Air Pressure Difference*
3. AAMA 501.1, *Standard Test Method for Water Penetration of Windows, Curtain Walls and Doors Using Dynamic Pressure*
4. AAMA 501.2, *Quality Assurance and Diagnostic Water Leakage Field Check of Installed Storefronts, Curtain Walls, and Sloped Glazing System*s
5. Electric Field Vector Mapping EFVM of waterproofing and roof membranes
6. High Voltage testing of waterproofing and roof membranes

Water Vapor Management:

1. ASTM C755, *Standard Practice for Selection of Water Vapor Retarders for Thermal Insulation*
2. ASTM E 1745, *Standard Specification for Plastic Water Vapor Retarders Used in Contact with Soil or Granular Fill under Concrete Slabs*
3. Wärme und FeuchteInstationär (WUFI Software)
4. ANSI/ASHRAE Standard 160, *Criteria for Moisture Design Analysis in Buildings*

Air-tightness:

1. ASTM E779, *Standard Test Method for Determining Air Leakage Rate by Fan Pressurization*
2. US Army Corps of Engineers air tightness testing protocol

Service Life:

1. Accelerated weathering by QUV – ASTM D4329, *Standard Practice for Fluorescent UV Exposure of Plastics*

2. ASTM D 4587, ISO 4892 Materials weathering tests – ASTM G155, ISO 4892

Acoustical:

1. ASTM E90, T*est Method for Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions and Elements*, http://www.astm.org/Standards/E90.htm
2. ASTM E966, *Guide for Field Measurements of Airborne Sound Insulation of Building Facades and Facade Elements*, http://www.astm.org/Standards/E966.htm
3. ASTM E1332 – 10a, *Standard Classification for Rating Outdoor-Indoor Sound Attenuation*, http://www.astm.org/Standards/E1332.htm
4. Department of Housing and Urban Development Noise Guidebook located at: http://portal.hud.gov:80/hudportal/HUD?src=/program_offices/comm_planning/environment/training/guidebooks/noise

5.1.11. Appendices

1. HPBDE Attribute-Metric-Performance Summary – Facility Operations (see Appendix A.1)

5.2 Structural Analysis

5.2.1 Introduction

Hazards, both natural and man-made, can pose significant threats to the serviceability and integrity of building enclosure systems. The objective of the structural analysis was to develop high-performance criteria related to conventional safety and protective security attributes for the planning of high-performance building enclosures in the DHS HPBDE OPR Tool.

5.2.2 High Performance Criteria

5.2.2.1 Attributes

The structural analysis focused on two EISA attributes: safety and security. Safety attributes are defined as natural hazards that impact the building enclosure including seismic, wind, flood and fire events. Security attributes are defined as man-made hazards that create structural loading on the building enclosure such as blast loading and ballistic loading.

5.2.2.2 Sub-attributes

Safety sub-attributes:

Seismic – The seismic sub-attribute is defined as environmental loading due to earthquake action, and examines issues related to the safety of the building enclosure against seismic-induced forces and movement. The performance of building enclosure cladding, glazing and roofing in earthquake events was considered. Below-grade construction is considered part of the building structural design and is not specifically developed in this phase of the tool.

Wind – The wind sub-attribute is defined as environmental loading due to wind action. The performance of building enclosure cladding, glazing and roofing in serviceability and extreme wind loading was considered. Extreme wind hazards reviewed are characterized by hurricane and tornado events and associated wind-borne debris hazards. Building damage from extreme weather events can cause considerable economic loss and operational disruptions for extended periods.

Flood – The flood sub-attribute is defined as environmental loading due to flood action. The performance of building enclosure cladding and glazing in flooding events was considered, specifically the impacts from flood duration, high velocity flow, flood-borne debris and associated degradation of enclosure materials.

Fire –The fire sub-attribute considers resistance and durability of the building enclosure against fire damage, possibly leading to consumption of the surface from fire, and spread of fire inside of the building as a result of unprotected openings and burn-through. This sub-attribute addresses hazards associated with three types of fire exposure, including adjacent buildings, wildfire hazards and neighboring storage facilities.

Security sub-attributes:

Blast – The blast sub-attribute is defined as an external blast caused by the detonation of high explosives that load the building enclosure. This sub-attribute addresses situations where the building is either the target of the attack or is located near the target and is loaded by a more distant blast.

Ballistic – The ballistic sub-attribute is defined as an attack against the building by an aggressor with a firearm. The scope of the attack is limited and will only affect a small area of facade components.

5.2.3 Demands

5.2.3.1 Safety Demands

Seismic – The Seismic Design Category (SDC) is the expression used in the demand model to measure an earthquake hazard in a particular region and categorize the associated seismic risk to building enclosure components. It should be noted that the SDC does not fully define non-structural component design as it relates to the building enclosure. Establishing enclosure component and anchorage design provisions is not the objective of the demand model. The SDC concept is used to set the relative demand levels and descriptions for seismic risk in the OPR Tool. The tool will allow the user to select options from the following matrix also linked to the geographic location of the proposed building:

Figure 5-1:
Seismic Design Class and Demand Level

SDC A	A	Low
SDC B	B	Medium-Low
SDC C	C	Medium-High
SDC D	D	High
SDC E/F	E/F	Very High

The SDC is the expression used in the demand model to measure an earthquake hazard in a particular region and categorize the associated seismic risk to building enclosure components.

The building enclosure should accommodate deformation of the structure as characterized by peak interstory drift during seismic events, as defined. Relative ranges for drift, displacement due to seismic loads, as well as component connection strength and deformation capability when subjected to seismic drift, will be further developed in the demand model in future iterations of this tool when building structure is specifically defined.

Wind – Wind loads on the building enclosure are a function of a number of factors including wind speed, exposure, topography, tributary area to the enclosure components, as well as building height and shape. Design wind loads are determined by prescriptive methods or wind-tunnel testing procedures specified by the applicable governing building code, often referring to ASCE 7. Ranges of wind pressures, as well as provisions for wind-borne debris in prescribed regions, were considered to establish the wind demand planning model. Extreme wind loading associated with tornado events was included as a separate item. For this planning tool wind demand pressures were calculated using the methodology presented in ASCE 7-05 for a range of representative buildings. As the OPR Tool is not intended for design purposes, certain assumptions were made in the development of the demand model. Representative buildings, nominally sealed, with flat roof surfaces and effective cladding wind areas of 60 SF were assumed for this tool. No allowances were made for open or broken windows, including from debris. This was prepared to set placeholder levels of demand. The tool will allow the user to select options from the following matrix:

Figure 5-2:
Wind Exposure and Demand Levels

	Exposure Category				
	Basic Wind Speed5	B	C	C	Demand Levels
I	85-90 mph	Low	Low	Low	Low 30 to 50 PSF
II	90-110 mph	Low	Medium	Medium	Medium = 50 to 90 PSF
III	110-130 mph	High	High	High	High = 90+ PSF + WBDR
IV	130-150+ mph	High	High	High	Special Case: Tornado

The wind load calculated is classified as Low, Medium, High or Extreme (Tornado is a special case). These designations are ranges characterized by maximum field of wall wind pressures. It should be noted that wind pressures are higher near corners, but for cost planning purposes the larger field of wall area should offer a more representative basis of demand for the overall enclosure. Also true is that component and anchorage design for typical field of wall areas can be scalable to work at corner zones. The more simplified approach with select options for exposure and wind speed was favored in this iteration of the model as information for mean building height and effective wind area were not included in the initial inputs by the user. These criteria should be incorporated in future versions of the tool to provide an added measure of refinement for wind demand.

6 These basic wind speeds are based on the 2005 edition of ASCE 7. If the 2010 edition is used, wind speed adjustments are needed. See Table C26.5-6 in ASCE 7-10 for correlation between 2005 and 2010 speeds.

Tornado events were given special consideration since, at a given location, they have a very high mean recurrence interval. It can be expected that, with the exception of glass breakage from wind-borne debris, a well-designed and constructed building should experience little damage from weak tornadoes. If the user perceives a risk, depending on the building use, hardening a portion of the building enclosure may be considered, although it is not a typical design provision. Tornado wind loading should be further developed as this tool is revised. Recommended inputs to refine tornado demand include an input for tornado region (yes/no), FEMA 361 wind zone and frequency maps (never in the past, rare, medium, frequent).

Flood – A qualitative flood demand profile was considered to characterize the building enclosure flood hazard based on inputs for velocity of floodwater, duration of previous flooding, maximum previous depth of floodwater, and floodplain area. The flood demand was mapped in the following categories: NA, Low, Medium, High, and Extreme. The interaction between the user inputs is identified in the OPR database. This iteration of the tool will allow the user to select options from the following matrix:

Figure 5-3:
Flood Demand Levels

Flood Demand Profile		
I	FEMA FIRM Map	Yes
		No
II	Floodwater Maximum Previous Depth FEMA Flood Insurance Study (FIS) Report	Never In Past
		Low
		Medium
		High
III	Duration of Previous Flooding	Never
		Short
		Medium
		Long
		Very Long
IV	Velocity of Floodwater Function of still flood depth (d_s) Low Bound: $V = d_s/t$ High Bound: $V = (gd_s)$^(0.5) Extreme: $V = 2(gd_s)$^(0.5)	Never in Past
		Low
		Medium
		High
		Extreme

Fire – A qualitative fire demand profile was considered to characterize the building enclosure fire hazard based on exposure to adjacent buildings, natural/forest fire and other fixed storage hazards (e.g. Fuel Storage Tanks). The fire demand was mapped in three categories: Low, Medium, and High. This iteration of the tool will allow the user to select options from the following matrices:

Figure 5-4: Fire Demand Levels

Adjacent Buildings	
Setback and fire resistance rating of wall, protected openings per code or neighboring building has sprinkler protection	Low
Inadequate setback or fire resistance ratings on 1 side	Medium
Inadequate setback or fire resistance rating on 2 or more sides	High
Natural /Forest Fire (WUI)	
> 100′ separation to forest	Low
30′-99′ separation to forest, BI*	Medium
I< 30′ separation to forest, BI*	High
Other Fixed Hazards	
Setback, protection provided for hazard	Low
Setback, no protection	Medium
2 sides, no protection	High

Note: *BI = Burning Index from US Forest Service

5.2.3.2 Security Demands

Blast – To enable building owners to select the relevant threat for their building a range of blast demands was considered. The blast demand is a function of the explosive charge weight (expressed in lbs of TNT) and the standoff distance from the detonation location to the target building. The design team selected a range of charge weights and standoff distances that correspond to historical terrorist threats and commonly used design criteria. The tool will allow the user to select options from the following matrix:

Figure 5-5:
Blast Demand Levels

		Charge Weight		
		Low	Medium	High
Range	25	M	H	Out of Range
	50	L	M	H
	250	Out of Range	L	M

The charge weight ranges used to develop the table are as follows:

Low Charge: ≤425lb TNT

Medium Charge: 425-2,500lb TNT

High Charge: 2,500lb-15,000lb TNT

The blast loading calculated once the charge weight and standoff are input is classified as L, M or H. These designations are ranges characterized by the impulse generated by the blast. The assumed ranges are as follows: L=20-50psi-msec, M=50-120psi-msec and H=120-400psi-msec. For consideration of threats outside the range of the table, calculate the blast impulse and select a setting from the table that results in a similar impulse. Threats in excess of the range listed and standoff distances less than those listed may result in an impractical enclosure design.

Ballistic – To meet ballistic standards building enclosure components are designed to resist a bullet from a defined firearm. Three demand levels were selected using the UL 752 standard. These levels are given the following designations:

Low: UL Level I - 9mm FMCJ w/ lead core

Medium: Level III - .44 Magnum lead SWC, gas checked

High: Level VII - 5.56 rifle, FMCJ with lead core

5.2.4 Baseline and Benchmarks

5.2.4.1 Safety Benchmarks

Seismic – The benchmark levels for seismic performance were established from a range of standards and references including ASCE 7-05, ASCE 41-06, NEHRP Recommended Seismic Provisions (2009), IBC-2009, and ASTM E 2026. The benchmarks relate to the level of damage that will occur during a seismic event ranging from major damage to minor/negligible damage.

Wind – The benchmark levels for wind performance were established from a range of standards and references including ASCE 7-05, ANSI

Z97.1, IBC-2009, and ASTM E 330, E 1300 and E 1996. The benchmarks relate to the level of damage that will occur during a wind event ranging from major damage to minor/negligible damage.

Flood – The benchmark levels for flood performance were established from a range of standards and references including ASCE 24-05, ASCE 7-05, IBC-2009, and NFIP. The benchmarks relate to the level of damage that will occur during a flood event, ranging from major damage to minor/negligible damage.

Fire – The benchmark levels for fire performance were established from a range of standards and references, including ASTM E119, ASTM E108, NFPA 251, ASTM E2707, NFPA 252, NFPA 257,NFPA 285, and IBC-2009. The benchmarks relate to the level of damage that will occur during a fire event, ranging from major damage to minor/negligible damage.

5.2.4.2 Security Benchmarks

Blast – The benchmark levels for blast performance are not taken from a single reference, but rather from a range of U.S. government and other references including UFC 4-010-01, PDC-TR 06-08, The ISC Security Criteria and the ASCE Blast Protection of Buildings Standard. The benchmarks relate to the level of damage that will occur during a blast event ranging from major damage to minor/superficial damage.

Ballistic – The benchmark for ballistic performance addresses whether the glazing or other enclosure component stops the threat bullet in accordance with the UL 752 Standard.

5.2.5 Metrics and Outcomes

Seismic – The metric that describes seismic performance is the level of damage and the expectation of continued operations. Damage levels are expressed as hazard levels. The anticipated outcome for each benchmark is described below.

> **ReB – Baseline –** Hazardous nonstructural and structural conditions may exist. Disengagement of cladding from the building may occur. Fracturing of glass and glass fallout may occur.
>
> **Re+ – Life Safety/Code Compliant –** Major, systemic damage to cladding may occur but cladding remains anchored to the building. The exterior wall system anchorage may deform, but catastrophic failure does not occur. Panels do not disengage from each other. Cracking and deformation to cladding may occur. Displacement and out-of-plane movements may occur. Seals and gaskets may tear/fallout and

ability to provide weather protection is globally compromised. Glass breakage and fallout may occur with non-safety glazing. The structure remains stable and has significant reserve capacity; hazardous nonstructural damage is significant but controlled. Occupancy is not expected after the event until repairs are performed.

Re++ – Reduced Damage – Moderate damage to cladding may occur but cladding remains anchored to the building. Seals and gaskets may tear and the ability to provide weather protection is locally compromised. Glass edge damage may occur and glass may fall off setting blocks, but glass breakage is mitigated. The building remains safe to occupy; structural and nonstructural repairs are minor. There should be no failure or gross permanent distortion of the building enclosure system anchorage and framing. Minor cracking and deformation of cladding may occur, but is not expected.

HRe – Continued Operations – There is negligible structural and nonstructural damage with minimal damage to cladding. Seals remain intact. Gaskets may be loosened but remain functional. No glass breakage is expected. The building enclosure system components remain in the same condition after the event as they were prior, with little or no repair or replacement needed.

Wind – The metric that describes wind performance is the level of damage and the expectation of continued operations. Damage levels are expressed as hazard levels. The outcome for each benchmark is described below.

ReB – Baseline – Hazardous nonstructural damage may exist. Moderate glass breakage may occur. Permanent deformation of cladding may occur. Damage may impact operations.

Re+ – Life Safety/Code Compliant – Hazardous nonstructural damage is controlled. Moderate damage to the building enclosure may occur. There should be no gross failure of building enclosure system anchorage. Minor deformation and permanent set of building enclosure elements may occur. No falling hazards should occur.

Re++ – Reduced Damage – Nonstructural repairs are minor. There should be no failure or gross permanent distortion of the building enclosure system anchorage. Moderate disengagement of gaskets and failure of sealants may occur. Minor cracking and deformation of building enclosure elements may occur, but is not expected. No falling hazards are allowed.

HRe – Continued Operations – There is negligible nonstructural damage. The building enclosure system components remain in the same condition after the event as they were prior, with little or no repair or replacement needed. There is no damage to the building interior.

Flood – The metric that describes flood performance is the level of damage and the expectation of continued operations. Damage levels are expressed as hazard levels. The outcome for each benchmark is described below.

ReB – Baseline –No floodproofing mitigation is provided. Severe damage and loss of operations is expected. A threat to occupants may exist.

Re+ – Life Safety/Code Compliant – Building enclosure damage requires major repair or reconstruction from exposure to floodwaters. The threat to occupants is reduced. Water damage to the building enclosure and the interior of the facility requires major cleanup, drying and repairs. Damage may prevent full occupancy of the facility for several weeks to months.

Re++ – Reduced Damage – The facility and building enclosure are affected by flooding within the design flood elevation. Damage is moderate. Cleanup, drying and moderate building enclosure repairs and/or replacement are required. The facility can resume service in a short length of time.

HRe – Continued Operations – The building sustains negligible nonstructural damage; the enclosure system is fully functional. The building is immediately operational. The site is not affected by erosion. Minor damage, debris or staining may remain, but repairs to the building enclosure are superficial.

Fire – The metric that describes fire performance is the level of damage and the expectation of continued operations. Damage levels are expressed as hazard levels. The outcome for each benchmark is described below.

ReB – Baseline – Major nonstructural damage exists. Fire has severely damaged the exterior enclosure and spread to the interior. Severe damage and loss of operations is expected. A threat to occupants may exist.

Re+ – Life Safety/Code Compliant – Hazardous nonstructural damage is controlled. The exterior wall system anchorage may deform, but catastrophic failure should not occur. Moderate cracking, melting and charring to the building enclosure may occur. Repair is possible, but may be economically impractical. Ignition of significant fire inside the building is likely.

Re++ – Reduced Damage – The building remains safe to occupy; structural and nonstructural repairs are minor. Systems with a one-hour fire resistance rating and unprotected openings are in place. Minor cracking, melting or charring of building enclosure may occur but is not expected. No falling hazards are allowed. There is ignition of minor items inside the building, but no spread from the initial item.

HRe – Continued Operations – Negligible structural and nonstructural damage. Systems with a two-hour fire resistance rating and protected openings are in place. The exterior wall system components remain in the same condition after the event as they were prior with little or no repair or replacement needed.

Blast – The metric that describes the blast performance is the level of damage and the expectation of continued operations. Damage levels are expressed as limits on ductility and end rotations of the component under examination. Glazing damage metrics are based upon hazard levels. The outcome for each benchmark is described below.

ReB – No Blast Protection – Enclosure components will fail in a hazardous manner.

Re+ – Major Damage – The enclosure is designed to resist the blast loading. However major damage to the facade will occur. There could be some areas of high hazard damage. The enclosure will require full replacement after a blast event. The building will not be operational.

Re++ – Moderate Damage – The building enclosure is designed to resist the blast loading, however facade components will be damaged. Some facade components will be repairable (such as the non-glazed façade and elements outside the most severe blast zone) while others will require complete replacement (glazing). Limited operations will be possible and recovery time will be shortened as compared to the Re+ level.

HRe –Minor/superficial damage – The building enclosure will only have minor or superficial damage after the blast event. Continued operations will be possible. Some repairs to the weather tightness of the building may be required (i.e. replacing gaskets or resealing joints).

Ballistic – After a ballistic event replacement of the affected facade element is expected. Repairs may be possible for some types of elements, such as concrete walls.

5.2.6 Performance Evaluation

To assist in establishing the performance levels identified in the OPR model, the performance of specific systems was evaluated and used to establish the general performance outcomes identified in the previous section and that are captured in the Appendix A.2: HPBDE Attribute-Metric-Performance Summary – Facility Resilience. Specific systems and their anticipated performance, as well as the range of costs for providing these systems to a proposed building, are evaluated here. These values populate the Technical and Financial Report generated by the OPR Tool for any scenario developed.

5.2.7 Systems for Meeting Demands/Resisting Threats

Seismic – A variety of strategies and methods can be used to deliver high-performing building enclosure systems designed to accommodate forces and dynamic racking movements characteristic of seismic events.

Glazing: Architectural glass that remains in the window opening during and following earthquake events should be characteristic of a high-performing building enclosure. Elements of high-performance glazing design for earthquake prone regions or area where increased performance is desired include a flexible frame to accommodate racking without damage and serviceability failure, bottom and side setting blocks, adequate glass to frame clearances, and structural silicone glazed-frame systems. Laminated architectural glazing in single lite and insulated glass unit construction was considered, for areas where high seismic performance is indicated. Other glazing constructions considered based on the desired level of demand and performance specified include, captured fully tempered heat-soaked, heat-strengthened and annealed units.

> Architectural glass that remains in the window opening during and following earthquake events should be characteristic of a high-performing building enclosure.

Opaque Wall: Seismic forces increase with the mass of the wall component and height of the component on the building. Seismic design objectives can influence the selection of the most appropriate building enclosure system for the project. Issues and solutions for heavy, intermediate and lightweight opaque cladding and fenestration

Seismic forces increase with the mass of the wall component and height of the component on the building.

assemblies were considered. Lower-cost opaque assemblies of steel studs faced with EIFS, stucco, brick or metal panels are generally not isolated in the same way as unitized systems of metal curtain wall or precast panels and may suffer considerable damage due to deformation of the structural frame. Theses lower-cost systems were considered at the low end of demand and performance. Controlling joint movement within the façade is a critical concern. The performance of the building enclosure in accommodating seismic-induced movements relies on the design of joints and the position and methods of attachment. Interstory drifts that occur in-plane are largely accommodated within façade enclosure movement joints. Interstory drifts that occur in out-of-plane should be accommodated by the flexure of the façade and rotation of the connections. Connections back to the structure should have adequate ductility, tolerance and rotation capacity to prevent deformation and cracking of enclosure components and failure of attachments.

Roof: Weight saving of the roof and braced roof/wall connections were considered to reduce the impact of seismic forces and improve performance, but there are many approaches possible. The roof assemblies considered were metal deck and reinforced concrete topping on metal deck.

Wind – A variety of strategies and methods can be used to deliver high performing building enclosure systems designed to resist hazards associated with wind, wind-borne debris and wind-driven rain.

Glazing: High-performing architectural glass should remain in the window opening during and following wind events. When high demand or performance is indicated as with wind-borne debris regions, breached building enclosures may be prevented by using storm shutters or laminated glass assemblies in properly glazed-frame systems. The gross deflection of glass-supporting frame members is also an important consideration in glazing designs. The larger the deflection of the frame under the wind load, the greater stress placed on the glass, increasing the possibility of breakage. The accepted design standard limit supporting the frame deflection is a maximum of L/175 of the clear span length of up to 13'-6" and L/240 + 1/4" at higher spans when subjected to design loads. Lower deflection ratios may also be specified, in particular with the use of some sealants or where extreme wind loads are anticipated. Reduction in allowable deflection typically requires the use of heavier frame cross-sections or reinforcements, which may change system cost and appearance.

As the wind load and wind-borne debris-resistant demands and/or desired performance level are increased, the thickness and treatment of glazing is increased.

Opaque Wall: A range of assemblies including steel studs faced with EIFS, stucco, brick and metal panels, and unitized systems of metal curtain wall and precast panels were considered. As the wind load and wind-borne debris-resistant demands and/or desired performance level are increased, the thickness, reinforcing ratio and connection strength of the cladding is increased, as is joint tolerance for wind-induced movement of the structure.

Roof: The roof assembly is assumed to be metal deck for the lowest wind demand loads and reinforced concrete topping on metal deck for the larger wind loading and/or higher sub-attribute performance levels. It should be noted that a high performance level could be achieved with both roof assemblies, provided adequate attention is given to detailing the roof structure anchorage and enhancement of the roof covering system, including incorporation of a secondary or reinforced membrane.

Flood – Dry-floodproofing and wet-floodproofing strategies for mitigating building enclosure flood damage were considered for this tool. The appropriate technique is ultimately the responsibility of the designers, based on applicable regulations and code requirements. These methods have greatly different implications on the building enclosure capital cost and event recovery recapitalization expense associated with different performance levels. Dry-floodproofing the building enclosure involves the use of special sealants and coatings, on walls and specialized components, such as flood shields and flood doors to make the lower portion of the building substantially watertight within the specified base flood elevation. For certain levels of demand and risk, where dry-floodproofing is not the appropriate option, wet-floodproofing may be preferred. Wet-floodproofing places the habitable space above the base flood elevation and allows the uninhabited lower portion of a building to flood. This requires flood damage-resistant materials in the lower, flooded portion of the building. A number of hydrologic and hydraulic conditions should be analyzed in selecting the suitable floodproofing strategy, including floodwater velocity, depth, duration, rate of rise, and flood-borne debris. Note that dry-floodproofing strategies were assumed

Dry-floodproofing the building enclosure involves the use of special sealants and coatings, on walls and specialized components, such as flood shields and flood doors to make the lower portion of the building substantially watertight within the specified base flood elevation.

Wet-floodproofing places the habitable space above the base flood elevation and allows the uninhabited lower portion of a building to flood.

for this model to obtain representative cost and interaction attribute ranges.

Glazing: Flood-resistant glazing should be capable of resisting impact from flood-borne debris, hydrostatic loads and dynamic wave action. The use of glass blocks, structural glazed laminate or polycarbonate glazing is assumed. System components, including gaskets, seals, locks, and finishes, should be resistant to floodwater and moisture damage.

Opaque Wall: The opaque wall cladding is expected to be nonporous, resistant to chemical corrosion or debris deposits, and easy to maintain. Moderately impermeable cladding material, such as hard brick, metal, and concrete was considered as acceptable. Framing and cladding are subject to the same flood-resistant requirements as all other materials. Anchorage and fasteners used within cladding systems should be a corrosion resistant type, hot-dip galvanized or stainless steel. Special sealants and coatings on enclosure walls should be provided.

Fire – A variety of methods and materials can be used to deliver high performing building enclosure systems designed to resist hazards associated with fire.

Glazing: Fire-resistant glass products should be incorporated into designs for improved fire performance; this includes fire-tested safety glazing, wired, tempered and laminated glass products. The application of smaller size insulated glazing constructions is considered to offer increased protection against transmitted heat as well as provide an integrity fire barrier for higher levels of performance.

Opaque Wall: The opaque wall cladding and anchorage should be fully insulated to resist failure and deformation due to increased temperatures. Enclosure components should be of non-combustible materials with low flame spread and smoke developed ratings for higher levels of performance. Special intumescent sealants and coatings on enclosure walls should be included in the design to seal holes and resist burn-through.

Blast – A wide variety of protective systems are available for resisting blast loads. Glazing systems are commonly constructed of laminated glass or polycarbonate. Opaque facades can be precast panels, cast-in-place concrete walls, reinforced masonry walls and cold formed steel stud walls with brick or metal panel veneer. Blast resistant roof structures range from metal deck at lower blast loads to metal deck with concrete topping or reinforced concrete slabs at higher blast loads. The following systems were assumed in the development of the OPR Tool:

Glazing: Blast resistant glazing is assumed to consist of laminated glass in blast resistant frames. The glass thickness and frame strength is increased as the blast demands or sub-attribute performance level is increased.

Opaque Wall: Non-glazed facade is assumed to consist of precast concrete panels. As the blast demands or sub-attribute performance level is increased, the thickness, reinforcing ratio and anchorage strength of the panels is increased. A variety of other systems can also meet the blast demands.

Roof: The roof is assumed to be metal deck for the lowest blast loads and reinforced concrete topping on metal deck for the larger blast loading and/or higher sub-attribute performance levels.

Ballistic – Ballistic threats can be resisted through the use of polycarbonate, glass or ceramics and ballistic rated walls consisting of concrete, masonry or steel plate. The following systems were assumed in the development of the OPR Tool:

Glazing: Ballistic glazing is assumed to be layups with layers of glass and polycarbonate to provide ballistic resistance. The thickness of the polycarbonate increases for increased demands.

Opaque Wall: Concrete walls were assumed for the OPR Tool. The concrete thickness increases as the demands increase.

5.2.8 Sub-attribute Performance Levels

Seismic – The following performance levels were considered for the sub-attributes. It is important to note that as the performance requirement of the building increases, consistent with ASCE7-05, the allowable story drift ratios for the structure actually decrease. To the extent that the building enclosure is required to accommodate deformation of the structure, demand may decrease, but other provisions for resiliency will need to be incorporated in the design, and will drive costs for improved performance. These costs are not considered by the OPR Tool at this iteration. See also the resilience summary spreadsheet in Appendix A.2.

Table 5-4: Seismic Performance Metrics

Performance Benchmark	Qualitative Metric	Quantitative Metric	Quantitative Values
Baseline	Extent of Damage and Continuity of Operations from a Design Basis Earthquake (10% Probability of Exceedance in 50 Years)	Glass Hazard and Enclosure Deformation Corresponding to Seismic Building Interstory Drift	> Code allowable story drift
Life Safety/ Code Compliant			Code allowable drift limits. Masonry shear wall structures: 0.007h. All other structures: 0.010h to 0.020h, where 'h' is story height
Reduced Damage			0.0075h to 0.01h
Continued Operations			0.004h to 0.0075h

Wind – The following performance levels were considered for the sub-attributes. See also the resilience summary spreadsheet in Appendix A.2.

Table 5-5: Wind Performance Metrics

Performance Benchmark	Qualitative Metric	Quantitative Metric	Quantitative Values
Baseline	Level of Damage /Continuity of Operations	Glass Hazard and Enclosure Deflection	Glazing hazard is moderate. Deflection > serviceability limits per code. Permanent deformation of cladding at overload (150% design load) > 0.2% of clear span. Major impacts to serviceability.
Life Safety/ Code Compliant			Glazing hazard is low (8/1000 breakage probable). Deflection within code limits of L/175 for frames supporting glass, L/240 for walls with brittle finishes, L/120 for walls with flexible finishes. Permanent deformation of cladding at overload (150% design load) < 0.2% of clear span.
Reduced Damage			Glazing hazard is minimal. Deflection less than code allowable. Permanent cladding deformation at overload (150% design load) < 0.05% of clear span.
Continued Operations			No glazing hazard. Deflection less than code allowable. No permanent cladding deformation at overload (150% design load). No impacts to serviceability.

Flood – Performance relating to flood hazard, vulnerability, and consequence is measured qualitatively in the OPR Tool, considering the level of damage and continuity of operations following a flood event. Refer to the resilience summary spreadsheet in Appendix A.2.

Fire – Performance relating to fire hazard, vulnerability and exposure is measured qualitatively in the OPR Tool, considering the level of damage and continuity of operations. Refer to the resilience summary spreadsheet in Appendix A.2.

Blast – The following performance limits were assumed for the sub-attributes. See also the resilience summary spreadsheet in Appendix A.2.

Table 5-6: Blast Performance of Systems

Laminated Glass

Benchmark	ASTM F1642 Performance Level	ISC Performance Level
Major Damage	Low Hazard	3B/4
Moderate Damage	Minimal Hazard/ No Hazard/Very Low Hazard	2/3A
Minor Damage	No Break	1

Blast Resistant Mullions

Benchmark	Ductility (μ)	Rotation (θ)
Major Damage	–	4°
Moderate Damage	–	2°
Minor Damage	1	–

Precast Concrete

Benchmark	Ductility (μ)	Rotation (θ)
Major Damage	–	4°
Moderate Damage	–	2°
Minor Damage	1	–

Metal Deck Roof

Benchmark	Ductility (μ)	Rotation (θ)
Major Damage	1.8	1.3°
Moderate Damage	1.5	1.0°
Minor Damage	1	–

Metal Deck with Concrete Topping Roof

Benchmark	Ductility (μ)	Rotation (θ)
Major Damage	–	2°
Moderate Damage	–	1°
Minor Damage	1	–

Ballistic – The performance limits for ballistic elements are based upon UL752. See also the resilience summary spreadsheet in Appendix A.2.

5.2.9 Cost Impacts

The cost impacts associated with enhanced levels of demand and performance for safety and security attributes were developed using previous project experience. In general, security and safety hardening can have a wide range of cost impacts based upon the baseline system.

Seismic – The OPR attempts to represent general trends for costs in safety construction. The following is a list of these types of trends:

- The cost of seismic hardening at higher floors may be equal to or greater than lower floors because façade enclosure component seismic forces typically increase with the height.
- Designing for minor seismic damage is significantly more expensive than designing for major seismic damage. Designing for moderate damage is slightly more expensive than designing for major seismic damage.
- Designing fenestration for increased resistance is not necessarily a larger cost delta than designing opaque facade as increased seismic

loads may be accommodated with added provisions for movement joint design and improved attachment rotation capacity.

- Major damage may require significant replacement cost while negligible damage associated with the highest performance requires minor cost to perform building enclosure repairs.

Wind – The OPR attempts to represent general trends for costs in safety construction. The following is a list of these types of trends:

- The cost of wind hardening at higher floors is greater than lower floors because wind speeds and associated pressures increase significantly with height.
- Designing for minor wind damage is significantly more expensive than designing for major wind damage. Designing for moderate wind damage is slightly more expensive than designing for major wind damage.
- Strengthening fenestration and glazing is a larger cost delta than strengthening opaque facade.

Flood – The OPR attempts to represent general trends for costs in safety construction. The following is a list of these types of trends:

- The cost of flood hardening specific to dry-floodproofing methods is higher at lower floors than upper floors located sufficiently above the base floodwater elevation.
- Designing for minor flood damage is significantly more expensive than designing for major flood damage. Designing for moderate flood damage is slightly more expensive than designing for major flood damage.
- Hardening fenestration is a larger cost delta than hardening of opaque façade, specific to the increased cost associated with impact-resistant glazing.

Blast – The OPR attempts to represent general trends for costs in protective construction. The following is a list of these types of trends:

- The cost of blast hardening at higher floors is less than at lower floors because blast loads decrease with height.
- Designing for minor blast damage is substantially more expensive than designing for major blast damage. Moderate blast damage is slightly more than major blast damage.
- Designing for an H blast load (~300psi-msec) will cost several times designing for a L blast load (~30psi-msec).

- Hardening glazing is a larger cost delta than hardening opaque facade.
- Major damage requires 100% replacement cost, while minor damage requires 5% of replacement cost to perform repairs.

Ballistic – The OPR attempts to represent general trends costs in protective construction. The following is a list of these types of trends:

- Ballistic glazing is very expensive.
- Providing ballistic glazing is a larger cost delta than providing a ballistic opaque facade.
- Ballistic glazing requires full replacement after an event. However, it is assumed that only a single window or a small number of windows are affected.

5.2.10 Interactions

Interactions between attributes were developed based upon discussions with other experts on the team. In general, structural safety and security interactions were highly correlated.

5.2.10.1 Safety sub-attributes

- Basement walls have shared interaction between seismic and flood safety attributes and protective blast.
- Roof structure for high seismic demand and performance interacts with the wind attribute and offers a relative small decrease in additive cost to achieve a high performing wind-resistant system. For example providing a high performing seismic resistant roof with braced roof/wall connections will provide an associated enhanced wind resistance.
- Roof structure for high wind demand and performance interacts with seismic attribute and may offer a relative small increase in cost to achieve a high performing seismic-resistant roof system. For example providing a heavy roof to resist high wind uplift forces may make the roof more vulnerable to seismic effects due to added mass where weight saving may be preferable.
- Safety attributes for opaque walls have a high level of shared interaction. Designing for high seismic performance may offer a relative small increase in additive cost to achieve a high performing flood-resistant and wind-resistant opaque enclosure.

- Safety attributes considering exterior fenestration have many interactions with other high-performance design attributes. Wind-resistant fenestration may reduce the costs of shared blast, seismic, flood and acoustic performance upgrades.

5.2.10.2 Security sub-attributes

- Basement walls only interact with other structural attributes (seismic and flood).
- Blast protected roof structures interact with wind and acoustic demands and reduce costs in both cases. For example providing a blast resistant roof with a concrete topping will provide enhanced wind resistance and also increase the acoustical performance of the roof.
- Blast protected opaque walls interact with wind demands only and reduce costs. Ballistic opaque walls interact with wind and blast and reduce costs. For example, providing a ballistic-rated concrete wall will increase the blast resistance of the wall and partially defray the blast hardening costs.
- Blast and ballistic protected fenestrations have the greatest quantity of interactions. Blast hardened fenestrations reduce the costs of simultaneous wind upgrades. However, it increases the costs of simultaneous thermal transfer upgrades. Similarly, ballistic upgrades reduce costs for wind and blast while increasing costs for thermal transfer. Ballistic glazing and natural ventilation are incompatible and cannot be used simultaneously.

5.2.11 Validation and Verification of Results

The best way to validate the OPR Tool for cost planning and interactions is to design trial projects where HPB principles are being implemented. Cost estimates should be developed for the baseline building and compared to estimates for an enhanced building. Trial projects should examine a range of building types and systems in multiple geographic regions and to determine the ranges of the tool.

The best way to validate the OPR Tool for cost planning and interactions is to design trial projects where HPB principles are being implemented.

5.2.12 Conclusions and Recommendations

The cost estimating portions of the tool require extensive validation before they can be unassailably relied upon. Cost estimates should be developed and compared for representative baseline buildings and high-performance enhanced buildings. Trial projects should examine a range of building types and systems in multiple geographic regions and further improve ranges of the tool. A number of existing limitations including geographic regions, the adaptability of certain systems and components to perform adequately under specific threats, limited repair/replacement of specific components and availability. Coordination between attributes of the tool and ongoing industry standards updates is recommended.

5.2.13 References

Seismic:

IBC-2009, “2009 International Building Code”

ASCE 7-05, “Minimum Design Loads for Buildings and Other Structures”

ASCE 41-06, “Seismic Rehabilitation of Existing Buildings”

NEHRP Recommended Provisions for Seismic Regulations

FEMA E-74, “Reducing the Risks of Nonstructural Earthquake Damage”

ASTME2026, “Standard Guide for Seismic Risk Assessment of Buildings”

Wind:

IBC-2009, “2009 International Building Code”

ASCE 7-05, “Minimum Design Loads for Buildings and Other Structures”

ASTM E 330, “Standard Test Method for Structural Performance of Exterior Windows, Doors, Skylights and Curtain Walls by Uniform Static Air Pressure Difference”

ASTM E 1300, “Standard Practice for Determining Load Resistance of Glass in Buildings”

ASTM E 1996, “Standard Specification for Performance of Exterior Windows, Curtain Walls, Doors, and Impact Protective Systems Impacted by Windborne Debris in Hurricanes”

ASTM E 1886, “Standard Test Method for Performance of Exterior Windows, Curtain Walls, Doors, and Impact Protective Systems Impacted by Missile(s) and Exposed to Cyclic Pressure Differentials”

Flood:

IBC-2009, "2009 International Building Code"

ASCE 7-05, "Minimum Design Loads for Buildings and Other Structures"

ASCE 24-05, "Flood Resistant Design and Construction"

NFPA 5000, "Building Construction and Safety Code"

FEMA, "National Flood Insurance Program"

Fire:

IBC-2009, "2009 International Building Code"

NFPA 251, "Standard Methods of Tests of Fire Resistance of Building Construction and Materials"

NFPA 257, "Standard on Fire Test for Window and Glass Block Assemblies"

NFPA 259, "Standard Test Method for Potential Heat of Building Materials"

NFPA 285, "Standard Fire Test Method for Evaluation of Fire Propagation Characteristics of Exterior Non-Load-Bearing Wall Assemblies Containing Combustible Components"

ASTM E108, "Standard Test Methods for Fire Tests of Roof Coverings"

ASTM E2707, "Standard Test Method for Determining Fire Penetration of Exterior Wall Assemblies Using a Direct Flame Impingement Exposure"

ASTM E119, "Standard Test Methods for Fire Tests of Building Construction and Materials"

Blast:

UFC 4-010-01, "DoD Minimum Antiterrorism Standards for Buildings"

UFC 3-340-02, "Structures to Resist the Effects of Accidental Explosions"

ISC Security Criteria

ASCE Blast Protection of Buildings

Ballistic:

UL 752, "The Standard of Safety for Bullet-Resisting Equipment"

5.2.14 Appendices

1. HPBDE Attribute-Metric-Performance Summary – Facility Resilience (see Appendix A.2)

5.3 Fenestration Analysis

5.3.1 Introduction

For buildings with appreciable amounts of glass – say 20% or more of wall area – fenestration performance can strongly impact the overall whole building energy performance. This fenestration report examines the energy conservation opportunities of high-performance fenestration criteria, and how such criteria interact, and can be compatible with, high-performance security criteria. Currently, fenestration is often considered "…the biggest hurdle ..." to achieving significantly higher levels of energy conservation and security for the building enclosure.[7] However, this negative assessment ignores two important sources of energy conservation for fenestration.

1. **Integration of Systems**: Substantial energy conservation and security opportunities are possible when fenestration is integrated with other building systems, using such integrated strategies as:
   - Daylighting (enclosure, lighting, interiors and controls)
   - Natural ventilation (enclosure, HVAC, controls)
   - Integration of enclosure and ventilation portions of HVAC systems

   This phase of the HPBD program does not include an extensive evaluation of natural ventilation and integration with HVAC for energy conservation and security criteria. However, key tools and resources have been developed in this phase that will provide a solid platform for evaluating these factors more thoroughly in subsequent phases when building services systems will be more fully evaluated.
2. **Research and Development (R&D)**: Several areas of fenestration research at research programs at Lawrence Berkeley National Laboratory (LBNL) and elsewhere have been identified with significant new energy conservation and security potential. LBNL has identified several areas where there is potential for major improvement in energy conservation of fenestration over the next decade, including:
   - Advanced, integrated daylighting
   - Affordable dynamic windows
   - Dynamic shading and glare control devices
   - Commercialization of cost-effective R5 windows

7 See Architectural section of this report, Section 3.3.

- Development of the next generation of R10 windows

This fenestration analysis identifies key performance criteria for fenestration. The attributes and sub-attributes of these criteria are discussed below in Sections 3 and 4 of this report.

The whole building results shown later in this report show the magnitude of the enclosure impacts on whole building energy performance.

This fenestration analysis also identifies the magnitude of impacts of specific enclosure measures on whole building energy performance. This is done via a set of parametric energy simulations which uses the EnergyPlus program on the medium office prototype building originally developed by Pacific Northwest National Laboratory (PNNL) to analyze the energy impacts of ASHRAE/IESNA Standard 90.1-2004 and 90.1-2010.[8]

This analysis isolates the energy performance impacts of enclosure options by holding steady the inputs for HVAC and lighting[9] across the parametric runs. **Thus, the whole building results shown later in this report show the magnitude of the enclosure impacts on whole building energy performance.**

Other architectural attributes and sub-attributes are covered primarily in the architectural section. These are listed below. Unless there is a specific reason to do so, we do not cover these in this fenestration section.

- Water penetration
- Air-tightness
- Service life
- Water vapor control
- Acoustical

8 ANSI/ASHRAE/IESNA Standard 90.1-2010. *Energy Standard for Buildings Except Low-Rise Residential Buildings*, Sections 9.4.1.4 and 9.4.1.5.

9 The simulations hold steady the installed capacities of lighting in spaces, in W/sf (W/sq.m.). Lighting energy use over time is reduced when sufficient daylight is available to maintain the desired illumination level. The desired illumination level has been maintained at the level established in the PNNL simulations of daylighting conducted to assess the prescriptive requirements of ASHRAE 90.1-2010.

5.3.2 High Performance Criteria

5.3.2.1 Attributes and Sub-attributes

Energy Conservation: the section evaluates this attribute for the impacts of fenestration systems by analyzing the following sub-attributes.

1. **Energy consumption:** This sub-attribute is measured as the impact on building energy consumption that can be attributed to changes in building enclosure features. This sub-attribute is further analyzed in the Architectural and Mechanical Sections. Estimates of the performance of this sub-attribute have been made using professional judgment. Estimates are also made here as part of the parametric energy simulations done to assess the impact of fenestration and opaque enclosure-related measures on enclosure performance.

2. **Daylighting:** This sub-attribute involves analyzing two levels of daylighting strategies. First, the impacts of basic daylighting strategies required by ASHRAE 90.1-2010 prescriptive requirements,[10] (which is very conservative) are assessed. In addition a range of more advanced, integrated daylighting strategies that have included various combinations of (1) advanced daylighting controls, (2) in some cases, include changes in building configuration and (3) changes in ceiling and window head height are assessed. Daylighting can be a very effective integrated design strategy that involves the building enclosure plus other building systems – lighting, interiors, solar and glare control devices, controls and HVAC.

   Shading to control solar heat gain and glare involves the use of fixed or dynamically controlled shading devices or dynamic windows. Whenever substantial window areas are used in buildings, as is typical of most office buildings, then the control of glare is important to occupant visual comfort with or without the use of daylighting. While this is an important aspect of enclosure performance, daylighting's cost and corresponding improvements in energy use are not directly included in the OPR Model in this phase of the HPBDE project. It is expected that daylighting will be covered in the next phase. In anticipation of this, it is modeled in the energy analysis.

3. **Natural ventilation:** This sub-attribute involves using hybrid and natural ventilation strategies that can involve operable windows, night flushing or other techniques to provide ventilation and thermal comfort conditions. This sub-attribute is especially attractive in the western US and Canada. However, the energy conservation impact

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10 ANSI/ASHRAE/IESNA Standard 90.1-2010. *Energy Standard for Buildings Except Low-Rise Residential Buildings*, Sections 9.4.1.4 and 9.4.1.5.

of this sub-attribute was not analyzed in this report. This sub-attribute is not at the same state of development as the other enclosure sub-attributes because (1) standards do not exist, and (2) easily-used computer simulation models are still under development and not widely available. Subjective predictions of the impact of natural ventilation on energy use were made but the effects of using natural ventilation were held to minimum levels due to current difficulties in validating performance with simulations or empirical analysis.

Integration of enclosure and mechanical ventilation systems was analyzed in the Mechanical Section. However, techniques such as airflow windows and double-skin facades were not part of that analysis and have not been analyzed in this section. The results in this report can be considered underestimates because these advanced techniques were not included.

5.3.2.2 Demands

1. **Energy Conservation:** The variable demand is Climate Zone. Latent loads and wet vs. dry vs. marine climates are significant influences for whole building energy consumption. To evaluate the impact of climate zones on whole building energy use related to enclosure insulation levels and fenestration performance, parametric energy simulations were conducted using EnergyPlus for a medium office building in:

   - 7 cities representing moist climate zones 1 thru 7,
   - 5 cities representing dry climate zones 2 thru 6, and
   - 3 cities representing coastal marine climate zones 3 thru 5.

   The medium office prototype building developed by PNNL was used for analyzing the energy impacts of ASHRAE/IESNA Standard 90.1-2004 and 90.1-2010. This analysis isolates the impacts of enclosure measures by holding steady the inputs for HVAC and lighting across the parametric runs. **Thus, the whole building results shown later in this report show the magnitude of the enclosure impacts on whole building performance.** The EnergyPlus simulations are summarized within this section and discussed in more detail in Appendix B EnergyPlus Simulation Analysis. Results from the medium office were interpolated using ranges and factors to account for the impact of changes in building size, from small to large office buildings. The results should be utilized with caution for buildings at extreme ends of

> The whole building results shown later in this report show the magnitude of the enclosure impacts on whole building performance.

the typical size range for office buildings. For further discussion of the impact of size, see the Appendix B analysis.

Whole building EnergyPlus simulation results are reported below for seven of the fifteen cities simulated in order to give an indication of the patterns of the building enclosure impacts. Results for all 15 cities have been simulated for the energy results summarized for selected cities in Appendix B.

The whole building simulation results were related to the broader categories by using energy results from a city most representative of the Climate Zone groupings. Depending on the attribute and components being modeled, and the differences in climate-based impacts, groupings of three and four climate zones were used in parts of the analysis. All results were either reported in four zones or interpolated to align with the following zones used in the OPR model:

- CZ 1 & 2
- CZ 3 & 4,
- CZ 5 & 6 and
- CZ 7 & 8

2. **Blast and Ballistic Protection.** Blast and ballistic demands on glazed assemblies can be addressed predominantly by adding laminated glazed layers. While this will substantially raise costs, only modest impacts on the visual and thermal properties of the glazing are expected. Conversely, strengthening window framing using such techniques as steel framing in place of aluminum, and limiting thermal break options, may have substantial negative impacts on the window thermal properties. Thus, blast protection may have more severe impacts on energy in colder climates than in warmer climates.

   Given the EnergyPlus parametric simulation resources that have been developed in Phase 1, tailored window assemblies can be created in subsequent phases that contain appropriate details for combinations of energy and blast/ballistic properties. Their energy impacts can be studied in detail using the EnergyPlus simulations.

3. **Noise, Contamination (CBR) Control, and Natural Ventilation:** Exterior noise and airborne contaminant exposures at the facility site become key factors for natural ventilation in conjunction with operable windows. This can be especially important in noisy or contaminated urban areas. In such areas or when risks of airborne contaminants are present, other options instead of operable windows

should be explored for providing outside air while minimizing noise or contaminant penetration. (Also see Architectural and Mechanical sections for analyses of noise and contamination/CBR issues).

4. **Daylighting:** Opportunities for using daylighting are treated as functions of the climate zone in this version of the OPR Tool. The proper use of daylighting involves an integrated design, construction and operations/maintenance effort across several building systems, including the enclosure, interior systems, building aspect ratio, window-wall ratio, fenestration height, devices to control glare and solar heat gain, control of lighting systems, and consideration of HVAC impacts. Many of these factors have already been examined in this phase. In future phases, when analyses of lighting and HVAC systems are conducted, a more extensive analysis of daylighting benefits is also planned. [11]

5.3.2.3 Baseline and Benchmarks

Fenestration is only a component, albeit a critical one, to achieve increasing levels of performance for many of the sub-attributes evaluated for the enclosure. As a result, baseline and benchmarks for fenestration are the same as those identified in the Architectural and Structural Analysis Sections for the attributes/sub-attributes of safety, security, energy conservation and durability covered in those sections and are not repeated here.

Fenestration is only a component, albeit a critical one, to achieve increasing levels of performance for many of the sub-attributes evaluated for the enclosure.

5.3.2.4 Metrics and Outcomes

Energy Metrics: There are three metrics commonly employed to measure energy use by buildings:

1. **Annual Energy Cost –** The cost to acquire the energy used by the building. ASHRAE 90.1 ECB method in Section 11 and Performance Rating Method in Appendix G, and USGBC's LEED Versions 2 and 3 all use the local annual energy cost to compare baseline building performance and proposed building performance.

2. **Site Energy –** The energy utilization intensity at the building site boundary, i.e., EUI in kbtu/GSF/yr year, calculated at the site.Site energy does not take into account conversion losses by fuel before reaching the site. GSA, the various 30% and 50% Advanced Energy Design Guidelines published by ASHRAE, and others, use site energy as a metric.

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11 See the recommendations for this section, which follow.

3. **Source Energy** – the energy utilization intensity at the building site boundary, i.e., EUI in kbtu/GSF/yr year taking into account the conversion and transportation cost of getting energy to the site. Source energy is considered by some to be a more balanced approach to fuels used by a building than site energy, since source energy considers a more complete, accounting of all of the energy used to provide the energy to the building. USGBC is proposing to use source energy as a key metric within LEED 2012 in tabulating energy prerequisites and credits.[12]

Site energy, the energy utilization intensity at the building site boundary, i.e., EUI in kbtu/GSF/yr, is the whole building energy consumption metric used in this report.

The fenestration thermal, infiltration, visual, acoustical and durability metrics utilized are reported in the Architectural Section 5.1

Blast and CBR Metrics: The metrics with which to measure security performance of the enclosure, including fenestration, are described in the Structural Section, 5.2. and Mechanical Section 5.4.

5.3.3 Systems for Meeting Demands/Resisting Threats

5.3.3.1 Fenestration assemblies – glazing and frame

Fenestration by itself – glazing and frame – currently is the biggest hurdle to achieving the desired energy conservation of the building enclosure, especially when constrained with security requirements. Recent fenestration requirements in codes and standards have been pushing toward cost-effective limits for traditional, non-dynamic and non-integrated fenestration solutions.

Fenestration by itself – glazing and frame – currently is the biggest hurdle to achieving the desired energy conservation of the building enclosure, especially when constrained with security requirements.

For heating climates:[13]
Technology is available to provide higher combined thermal and visual performance, but at substantially increased cost. For example, the current highest performing glazing is quadruple glazing, with heat mirror foils and krypton gas fill. Some cost savings can potentially be obtained from use of triple and quadruple glazing systems in colder climates by the elimination of perimeter heating systems.

12 LEED 2012, *LEED Rating System, 2nd Public Comment Draft, Building Design & Construction*, includes: New Construction, Core & Shell, Schools, Retail, Data Centers, Warehouse & Distribution Centers, Hospitality, Healthcare, pp. 81-88, July 2011.

13 Objectives by climate are adapted from LBNL windows research technical objectives.

Recent research in the LBNL windows and daylighting program has been focused to commercialize cost-effective R5 windows (U=0.2) and to develop the next generation of R10 windows (U=0.1). Targets for this research are highly insulated windows of 25 SF or more in size and U= 0.10, at an increased Insulated Glazing (IG) cost of $4/SF in 2015 and $3/SF in 2020.[14]

Frame strength versus energy performance is another hurdle in cold climates where more thermal energy is typically transmitted through the framing system rather than the glazing. When blast resistance requirements are added to the framing, energy performance can deteriorate further.

Frame strength versus energy performance is another hurdle in cold climates where more thermal energy is typically transmitted through the framing system rather than the glazing.

For cooling climates:
The objective is to reduce cooling loads via use of very low SHGC, while increasing the visible light transmitted to increase daylight harvesting, and transitioning from static solar control (e.g. fixed overhangs) to dynamic solar control.

For mixed climates:
A key objective is to use dynamic solar control to reduce cooling loads when necessary while allowing solar gains to occur when beneficial but without glare.

For all climates:
Include daylighting to enhance the visual environment while reducing the use of electric lighting.

5.3.3.2 Fenestration Systems:

With the exception of daylighting, the above analysis addresses only the glazing and framing of the fenestration system. However, the most energy-effective fenestration systems include more than just the glazing and framing. Currently, the most promising energy conserving opportunities for fenestration systems are from the following items (Note: the items followed by asterisks (*) are not included in this phase of the HPBD project but are intended to be included in subsequent phases:

1. Static solar control (overhangs) (fins*)
2. Dynamic solar control

   Dynamic shading devices*
   Dynamic windows, notably electro-chromic windows*

14 From presentations by S. Selkowitz, LBNL, 2009-2010

3. Enclosure systems integrated with ventilation, including air flow windows and double-skin facades*

4. Natural ventilation systems, especially for dry mountainous regions and coastal marine climates*

5. Integration of enclosure systems with other building systems. Daylighting interacts with several building systems:

   - Fenestration apertures and locations
   - Static and dynamic shading devices and their controls*
   - Lighting systems and controls
   - Glare and shading devices and their controls*
   - Interior systems including
     - Space use and dimensions
     - Surface reflectance and specularity*
     - Furniture arrangement*
   - Partition height, location and opacity*

5.3.4. Performance Targets for Sub-attributes

5.3.4.1 Thermal Transfer Performance Targets for PB, P+, P++ and HP

- **Building opaque wall and roof U-Factors –** Analysis of the target levels of benchmark performance for opaque walls and roofs are included in Appendix B and are employed in the calculations of whole building and enclosure only performance that follow.

- **U-Factor performance criteria for building fenestration –** Table 5 7 below shows the U-Factor criteria for the fenestration assembly (center of glass, edge of glass, and frame). The U-Factor criteria improve with each performance level. In climate zones 1 through 6, the improvement in U-Factor thermal performance level from the (PB) Baseline of 90.1-2004 to the (HP) High Performance case is about 40%. In climate zones 6 and 7, the Enhanced and High Performance thermal performance levels propose substantial improvements in fenestration U-Factor performance via the use of the highest performance fenestration assemblies available. The HP High Performance thermal performance case assumes the use of a quadruple pane glazing system with a U-Factor of 0.10.

Table 5-7: Building Fenestration U-Factor Criteria

U-Factor (Btu/ft2°F hr)				
Climate Zones	Baseline (PB)	(P+) Improved	(P++) Enhanced	(HP) High Performance
CZ 1, 2, and 3	0.70	0.60	0.50	0.40
CZ 4, 5, and 6	0.40	0.35	0.30	0.25
CZ 7 and 8	0.35	0.20	0.15	0.10

- SHGC thermal performance criteria for fenestration – SHGC thermal performance criteria for the fenestration assembly (center of glass, edge of glass, and frame) alone and including external, integral or internal shading devices are evaluated as part of the analysis for achieving the enhance performance levels. However, the effects of SHGC are currently not included in the OPR model that is part of this overall Phase 1 project effort. The evaluations in variations in SHGC provide useful information as a basis for adding SHGC more directly into the OPR Tools in subsequent phases of this project. Results are reported in Appendix B.

5.3.4.2 Daylighting Performance Targets for PB, P+, P++ and HP

Key daylighting criteria for the perimeter zones of a typical office building are identified in Table 5 8. The use of automatic daylighting controls and related integrated design solutions can be a very effective strategy when compatible with building program requirements.

Key factors and performance criteria include:

- **90.1-2004 (PB energy performance) –** No daylighting is required, so none is installed.
- **90.1-2010(P+ energy performance) –** Basic daylighting is required by the prescriptive requirements of 90.1-2010.
- **Improved Performance (P++ energy performance) –** More advanced daylighting control is used, with 65% of the building gross floor area using automatic daylighting controls to reduce electric lighting energy use
- **Improved Performance (HP energy performance) –** More advanced daylighting is used, with 77% of the building gross floor area using automatic daylighting controls to reduce electric lighting energy use.

Table 5-8: Daylighting Thermal and Visual Performance Criteria

Climate Zones	Baseline (PB)	(P+) Improved	(P++) Enhanced	(HP) High Performance
CZ 1, 2, and 3	N/A	51%/15 ft/50%	65%/20 ft/50%	77%/20 ft/60%
CZ 4, 5, and 6	N/A	51%/15 ft/50%	65%/20 ft/50%	77%/20 ft/60%
CZ 7 and 8	N/A	51%/15 ft/50%	65%/20 ft/50%	77%/20 ft/60%

5.3.5 Energy Performance Evaluations of Sub-attribute s

5.3.5.1 Energy Modeling Methodology using EnergyPlus

The original objective of the Fenestration analysis for Phase 1 was to use professional judgment to develop performance metrics and criteria for fenestration assemblies. Then, during the conduct of Phase 1, the opportunity arose to use inputs of building prototypes for the EnergyPlus simulation program that had been developed by PNNL with DOE funding. The Fenestration Committee began using the medium office prototype from PNNL as the basis for conducting a systematic parametric analysis of the impacts of the building enclosure measures on overall whole building energy use. This exploratory task was added to the scope of the fenestration analysis to provide validation/verification for the whole building energy use predictions and the corresponding portion attributable to the enclosure made as part of the architectural and mechanical analyses. It has been limited to simulations of the medium office prototype and to exploratory simulations of key enclosure parameters, especially advanced energy conservation measures that could be simulated without developing extensive new input sequences.

The analysis uses the EnergyPlus simulation program as applied to a prototypical medium size office building. This prototypical model describes a three-story building of 53,628 GSF that is modeled using 5 zones per floor, resulting in a floor plate of approximately 17,900 SF. The prototype received from PNNL has an aspect ratio of about 1.5:1, with long sides facing north and south, and continuous strip windows with a baseline window-to-wall ratio (WWR) of 0.33. Appendix B analyzes the whole building energy performance impacts of four levels of WWR, at 0.20, 0.33, 0.40, and 0.6, two levels of window head height (i.e., 9’ and 11’ AFF), and two levels of building aspect ratio (i.e., 1.5: 1 and 3:1).

A 3D image of the building model with 1.5:1 aspect ratio and 0.33 WWR is shown below.

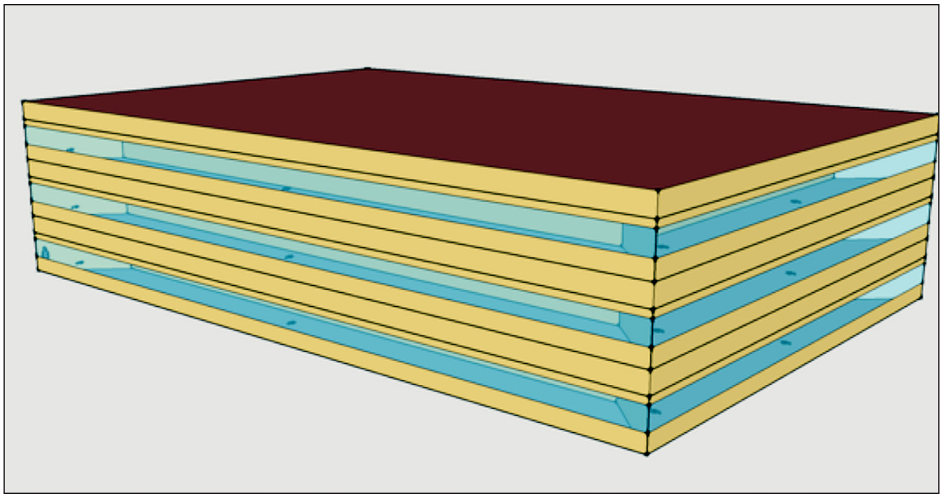

Figure 5-6:
PNNL Model Building

The medium size reference office building developed by PNNL is one of some 16 building types[15] recently analyzed by PNNL as part of an assessment by DOE of the energy levels obtained by ASHRAE/IES 90.1-2004 and 2010. Using the EnergyPlus simulation approach summarized in the previous section, simulations have been conducted during the Phase 1 exploratory effort for several individual energy conservation measures for fenestration as well as combinations of some of the measures.

1. **Whole building energy impacts of changing enclosure features from 90.1-2004 to 90.1-2010**

   Using the simulation methodology described above, the fenestration analysis developed whole building energy conservation results for changing just building enclosure features from the mandatory and prescriptive requirements of 90.1-2004 to those of 90.1-2010. For consistency, other building system features at the 90.1-2010 Level were maintained. This analysis is summarized below in Section 5.2 and is described more fully in Appendix B.

2. **Individual enclosure energy conservations measures examined in Phase 1**

   Using the simulation methodology described above, a number of the following individual building enclosure energy conservation

15 The building types include small office, medium office, large office, warehouse, strip mall retail, standalone retail, primary school, secondary school, outpatient healthcare, hospital, small hotel, large hotel, quick-service restaurant, full-service restaurant, mid-rise apartment, high-rise apartment.

measures (not constrained by any specific safety or security requirements) have been examined during Phase 1. These include:

- Reduced infiltration
- Advanced roof and wall insulation
- High performance 2-pane, 3-pane, and 4-pane windows, with either low U-Factor values or high visible transmittance values, or both.
- Fenestration assemblies supplemented by fixed external shading (overhangs).
- Fenestration assemblies supplemented by dynamically controlled external shading (overhangs).
- Dynamic windows, using electrochromic technology
- Basic daylighting measures that meet the new prescriptive requirements for daylighting incorporated into ASHRAE/IES Standard 90.1-2010.
- Advanced daylighting that considers three ways, separately and together, to increase daylighting effectiveness beyond the basic requirements for daylighting use listed in Section 9 of 90.1-2010, namely:
  - Using better daylighting controls other than the minimum prescriptive daylighting requirements of 90.1-2010.
  - Increasing window head height to increase daylighting penetration from 15 feet to 21 feet from the exterior walls, without increasing window area, which could increase heating / cooling.
  - Elongating the building in the east-west direction to increase perimeter area along the north and south facades.
- Variations in WWR.

These analyses are summarized below in Sections 5.3 to 5.5 and are described more fully in Appendix B. These simulations of individual measures should not be considered estimates of potential P++ or HP level energy performance. Rather they should be considered simply as explorations of the possible, selected individual high-performance enclosure options.

3. **Limited Analysis of Natural Ventilation**

   Due to modeling complexities, the approach precluded the development of simulations to measure the performance of natural ventilation. This is discussed further in Appendix B.

4. **Combinations of enclosure measures to represent potential P++ and HP enclosure energy performance levels**

   Again using the simulation methodology described above, fenestration analysis analyzed the whole building energy conservation impacts of combinations of enclosure measures intended to provide a draft, Phase 1 indication of potential P++ and HP enclosure energy performance levels. These analyses are summarized below in Section 5.6 and are described more fully in Appendix B.

5.3.5.2 Energy Benchmark Evaluations of 90.1-2004 (PB) to 90.1-2010 (P+)

90.1-2004 (PB) to 90.1-2010 (P+) – Enclosure measure impacts on whole building % savings: As illustrated in Figure 5-7 below, changes in enclosure prescriptive requirements from 90.1-2004 to 90.1-2010 are estimated to be capable of producing from 5.5% to 9% whole building energy consumption savings.[16]

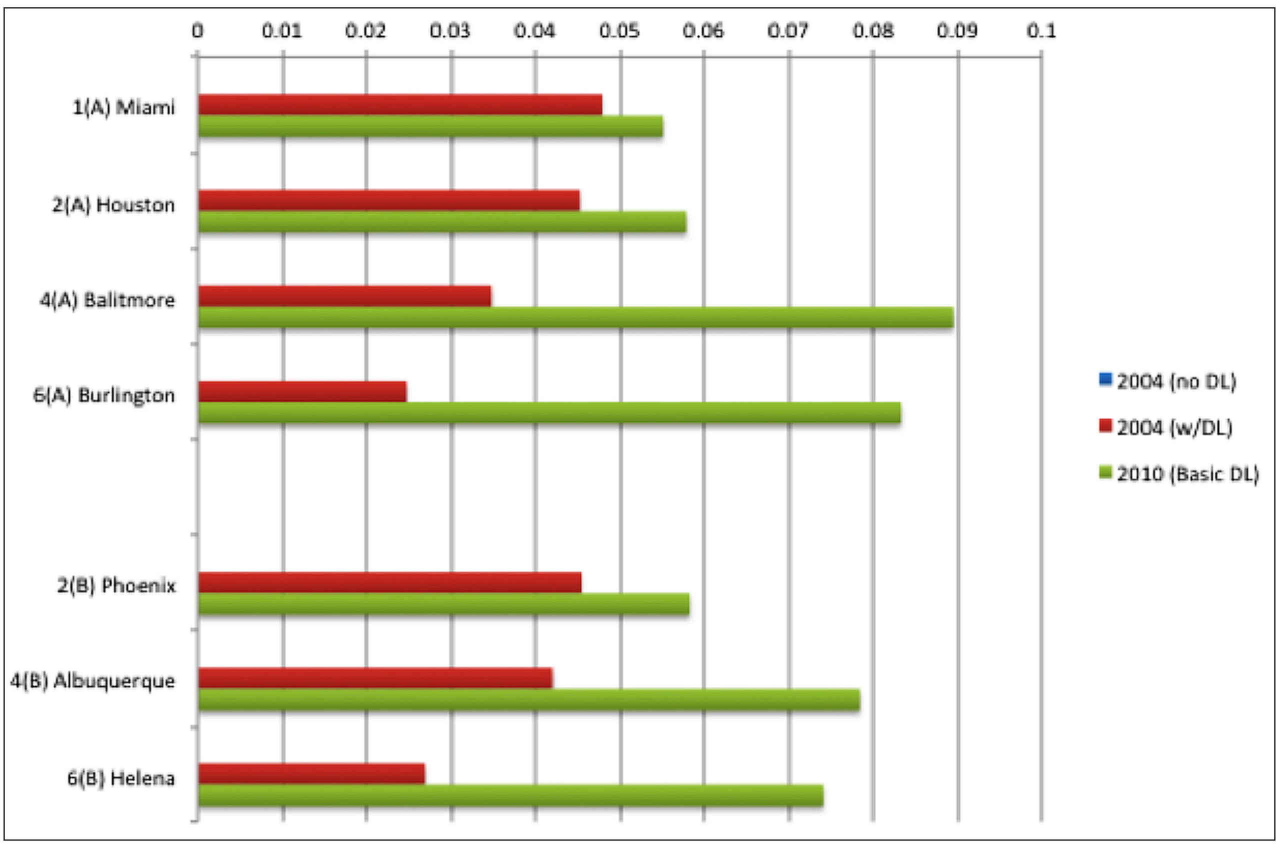

Figure 5-7:
Whole -Building Energy Impacts of (P+ Energy Performance) Improvement over 90.1 2004 Baseline

16 The ASHRAE Standard 90.1 Envelope Subcommittee had planned for more savings.

90.1-2004 to 90.1-2010 (P+ energy performance): Compared to the baseline of 90.1-2004, the combined prescriptive enclosure measures contained in 90.1-2010 produced:

1. A range of annual site energy savings in EUI from 5.5% to 8.3%, compared to PB energy consumption estimates (i.e., targets).
2. The percentage of site energy savings was lower in cooling dominated climate zones 1A, 2A, 2B and higher in temperate and heating dominated climate zones 4A, 4B, 6A, 6B.
3. Continuous air barriers alone produced a range of annual site energy savings in EUI from 0.3% to 3.7% compared to the PB energy consumption targets. Percent savings were significantly higher in northern climate zones.
4 Basic daylighting alone produced a range of annual site energy savings from 2.5% to 4.8%. Percent savings were significantly higher in the cooling dominated southern climate zones.
5. For source energy, the percent savings were from 5.7% to 9.2%, and there were greater savings in cooling-dominated southern climates than for site energy.

More detail is provided in Appendix B of this report.

5.3.5.3 Energy Benchmark Evaluations of Selected Fenestration Enclosure Performance Improvement Measures

Using EnergyPlus, parametric results for selected individual and combined enclosure enhancement measures that identify the extent of improvement in whole building energy performance of the enclosure improvement measures were calculated. Individual building enclosure improvement measures were isolated and analyzed using the EnergyPlus model and are reported in Appendix B. Runs were made using the (P+) modified reference building that includes 2010 vintage HVAC and lighting in all cases. Improvements evaluated were:

1. Non-Fenestration advanced improvements (air Barriers and insulation)
2. Individual and combined advanced fenestration improvements (high performance windows)
3. Window-to-wall ratio changes from 0.20 to 0.60
4. Advanced daylighting with change in building form

The values obtained from the analysis by isolating contributions to energy savings for each improvement individually were utilized in the analysis that follows of whole building and enclosure-only energy use anticipated at each overall project performance benchmark level.

5.3.5.4 Whole building energy simulation results for combinations of measures representing the four energy performance levels – PB, P+, P++, and HP.

Combinations of high-performance measures were simulated in EnergyPlus in order to provide an estimate of how much whole building energy conservation savings might be obtained at each of the three advanced levels (P+, P++, and HP) from the baseline level (PB).

The following is a draft set of parametric results from EnergyPlus for selected high-performance enclosure measures (i.e., thermal performance levels) across the three benchmark energy performance levels (P+, P++, and HP). The estimates below use the modified reference building that includes 2010 vintage HVAC and lighting in all cases in order to isolate the impacts of the building enclosure measures.

For the P+ Level, the combined enclosure measures and features are defined by the set of ASHRAE/IES 90.1-2010 mandatory and prescriptive requirements:

1. Prescriptive daylighting controls.
2. No overhangs
3. Infiltration = 0.1
4. Window features set by values used in PNNL Reference Building
5. Opaque enclosure measures set by values used in PNNL Reference Building

For the P++ level the combined measures and features are:
For all climate zones:

1. Improved Continuous daylighting controls, but the window head height is not increased and the building aspect ratio is not changed
2. Infiltration = 0.1
3. Improved opaque enclosure measures to P++ level as shown in Table 5 7.

Plus for CZ 1, 2:

1. Overhang, 50% Penetration Factor (PF)
2 Double pane window #1: U = 0.36, SHGC = 0.25, Tv = 0.57

Plus for CZ 4:

1. No overhangs
2. Double pane window #2: U= 0.35, SHGC = 0.35, Tv = 0.62

Plus for CZ 6,7:

1. Overhang, PF = 0.25
2. Double pane window #2: U= 0.35, SHGC = 0.35, Tv = 0.62

For the HP level, the combined measures and features are:
For all climate zones:

1. Improved Continuous daylighting controls, but window head height not increased and building aspect ratio not changed
2. Infiltration = 0.1
3. Improved opaque enclosure measures to HP level as shown in Table 5 7

Plus for CZ 1, 2:

1. Overhang, PF = 0.75
2. Quadruple pane window: U= 0.1, SHGC = 0.29, Tv = 0.45

Plus for CZ 4:

1. No overhangs.
2. Quadruple pane window: U= 0.1, SHGC = 0.29, Tv = 0.45

Plus for CZ 6,7:

1. Overhang, PF = 0.25
2. Triple pane window: U= 0.14, SHGC = 0.47, Tv = 0.61

Percent Energy Conservation Savings, Site Energy:

The above combinations of measures produced the site energy results shown in Table 5-9 and in Figure 5-8.

Compared to the PB baseline of 90.1-2004 (no daylighting), the percentage reduction in whole building site energy consumption is in the following ranges:

- The P+ (90.1-2010) level results in percent reductions of 5.5% to 16.0%.
- The P++ (Enhanced) level, results in percent reductions of 13.5% to 21.8%.
- The HP (High Performance) level, results in percent reductions of 14.0% to 25.8%.

The greatest percent reduction by far occurred in northern heating-dominated climate zone 7 (Duluth).

Table 5-9: Percent Reduction in Whole Building Energy from Combined Packages of Measures Intended to Represent P+, P++, HP Levels

Percent Savings from Base (Site Energy) Base used ---> 2004 no DL	(PB) 2004 no DL	(P+) 2010 with DL	P++	HP
1 (A) Miami		5.5%	14.3%	18.7%
2 (A) Houston		5.8%	14.2%	18.1%
4 (A) Baltimore		8.9%	15.4%	15.1%
6 (A) Burlington		8.3%	17.6%	20.1%
7 (A) Duluth		15.9%	21.8%	25.8%
2 (B) Phoenix		5.8%	16.1%	20.2%
4 (B) Albuquerque		7.8%	13.5%	14.0%
6 (B) Helena		7.4%	16.8%	19.4%

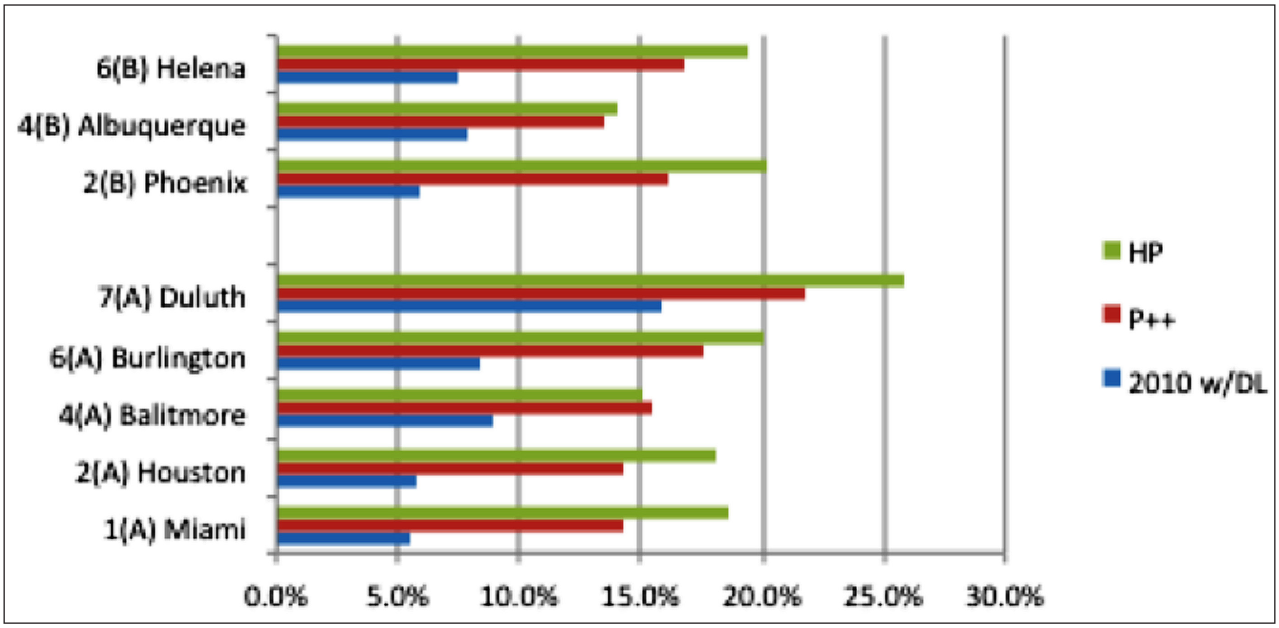

Figure 5-8: Whole Building Results of Combined Measures for P+, P++, and HP Site Energy

These modeled values for whole building energy savings from building enclosure improvement measures are somewhat higher than the projected percentages of EUIs attributable to the building enclosure, as shown in Table 5 14 Expected Ranges Across Climatic Zones of EUI Targets and Corresponding CO_2e Values, and Percentages Attributable to the Opaque and Glazed surface Areas of the Building Enclosure at Minimum/Low Level of CBR protection (FSL I/II) in the Mechanical Report, owing to the different methodologies employed in developing the values. The modeled values are believed to represent a more accurate estimate of anticipated performance and are reflected in energy savings calculations in the OPR Tool.

5.3.6 Cost Impacts

Capital expense and maintenance and operating costs of fenestration systems at the defined levels of performance (i.e., Baseline, P+, P++, and HP) were developed as part of the architectural analysis. Results of the benchmark modeling process were used to help establish ROI for the sub-attributes of thermal transfer, air tightness, daylighting and natural ventilation.

5.3.7 Interactions

This report examines several important interactions between the building fenestration system and other building systems. The EnergyPlus simulation results shown above, and in Appendix B, demonstrate the results for a set of enclosure parameters analyzed both individually and in combination. This includes daylighting, a key energy strategy that involves the interaction of several building systems.

5.3.8 Validation and Verification of Results

This report describes significant EnergyPlus whole building parametric simulation analyses that have been conducted in an effort to validate and verify the magnitude of whole building energy impacts of key enclosure energy-related measures. The simulation team considers the parametric simulation effort to date to be a successful initial effort to validate and verify, and anticipates refined and expanded results in subsequent analyses.

5.3.9 Conclusions and Recommendations

The following conclusions and recommendations result from the Fenestration analysis:

5.3.9.1 Conclusions:

1. **Individual enclosure measures:** Reductions in whole building energy consumption (site energy), attributable to individual options for the thermal design of the enclosure, have been projected by modeling and simulations to range from 5-15%, compared to the ASHRAE 90.1-2004 baseline.

2. **Bundles of enclosure measures:** These were also analyzed by simulation for P+, P++, and HP levels. Compared with the ASHRAE 90.1-2004 PB baseline, predicted reductions in whole building energy consumption had the following ranges for site energy:
   - For P+, reductions of 5.5% to 15.9%
   - For P++, reductions of 13.5% to 21.8%
   - For HP, reductions of 14% to 28.5%
3. The whole building energy reductions in this fenestration report are for enclosure measures in isolation. This is an important contribution of this fenestration report. In this regard, the reductions reported here are different from those reported by the architecture and mechanical reports, which have also included combined HVAC and lighting improvements.
4. These estimated whole building energy reductions shown in this fenestration report have a solid foundation in data generated from systematic parametric energy simulations. The results generated appear to show higher levels of energy conservation from enclosure measures than those reported by the HPBDE Mechanical Committee.
5. The range of advanced enclosure measure examined in this technical report are more extensive and more robust than those identified in the PNNL AEDG 50% reports for small and medium office buildings. Thus, enclosure measures reported in the PNNL reports are likely to produce less energy reductions than the reductions reported here.
6. Relative to the percentage of whole building energy use attributable to thermal design options for the building enclosure it may also be inferred from these Phase 1 analyses that interactions between the thermal performance of the enclosure and CBR and Blast sub-attributes are likely to have:
   - Only minor impact in cooling-dominated southern climate zones, since additional laminated glazing layers may have only minor negative impact on SHGC and VLT performance.
   - Potentially major impact in heating-dominated northern climate zones, because blast-resistant window framing may have substantially reduced thermal performance.

   Further simulation-based examination of these potential impacts is planned for subsequent phases of this project.
7. In general, the modeling rules in 90.1 Appendix G have in the past ignored glare considerations irrespective of use of daylighting.

However, glare-related modeling rules have recently changed in the 90.1-2010 version of Appendix G. Glare can be a serious issue for visual comfort when large window areas are used, as is common in office buildings. While not all Phase 1 daylighting analyses addressed glare controls, the combined analyses described in the advanced daylighting analysis referenced in section 5.3 above and detailed in full in Appendix B to this report did include external shading plus daylighting for most climate locations. The external shading did provide some glare control, relative to the non-daylighting cases. This topic is discussed in more detail in Appendix B. Further examination of this issue is planned for future phases of this project.

5.3.9.2 Recommendations

1. **Advanced Fenestration Features:** Further analysis should be done of high-performance impacts of several advanced fenestration features, including:

    a. Advanced window systems, including 2-pane, 3-pane and 4-pane options, with special attention to appropriate combinations of SHGC, TV and U-Factors by climate.

    b. Dynamic external shading devices, in particular dynamic external louvers.

    c. Dynamic glazing options, both thermochromic and electrochromic.

    d. Interactions of fenestration systems with HVAC systems

    e. Combinations of advanced daylighting solutions, including various combinations of:

        - Advanced daylighting controls and systems
        - Advanced glare controls and devices
        - Building form
        - Interior design and spatial dimensions

    f. Natural and hybrid ventilation systems. In particular, future phases of this project should explore:

        - Possible new guidelines and standards that may be emerging
        - The possible use of new NV/HV simulation models now being developed at Berkeley Lab (LBNL) with funding from the California Energy Commission[17]

17 Based upon verbal communications with Philip Haves, Director of the Simulation Group at LBNL.

2. **More Detailed Comparison with Enclosure Measures in PNNL 50% Reports:** The energy reductions for the sets of energy measures in the PNNL reports should be identified separately from the measures from the other systems. Those reductions should be compared with the reductions for the measures being examined here and in subsequent phases. Ideally, the reference building input files can be obtained from the PNNL team and used as a basis for additional parametric simulations of the whole building energy performance impacts of specific individual energy conservation measures. This can include measures for enclosure, lighting and HVAC systems. If obtaining the input files from PNNL is not possible, input files can be developed based upon input data descriptions in the various PNNL reports. In this case, review by the PNNL team to insure that the interpretations made are appropriate should be requested.

3. **Refine and Expand Parametric Simulation Resources**: The parametric simulation modeling tools and resources developed in this phase should be refined and expanded in future phases. The current methodology and resources developed in Phase 1 include:

   a. The creation of a single EnergyPlus parametric input file with the lighting and HVAC features fixed at ASHRAE 90.1-2010 prescriptive requirements in order to establish a solid methodological framework for doing a wide range of individual and combined energy simulations for the building enclosure.

   b. The creation of a set of parametric processing "scripts" for generating and reporting on a variety of EnergyPlus parametric simulations.

   c. The successful application of the input file and the scripts across a wide variety of parametric simulations of individual and combined building enclosure features including:

      - Opaque roof insulation at P++ and HP levels
      - Opaque wall insulation at P++ and HP
      - Individual advanced fenestration selections for 2-pane, 3-pane and 4-pane solutions
      - Fixed external shading
      - Preliminary analysis for dynamic shading and for dynamic windows, although a more sophisticated analysis is needed to validate the results.
      - Daylighting, with options that examine just advanced DL controls; controls plus increased head height, and controls, head height and building shape change to 3:1 AR (aspect ratio).

d. The methodology, and the parametric tools developed so far, form a valuable resource that can be used in future phases of this project (and others) for a wide range of analyses such as:

- Additional enclosure analyses in future phase of this project
- Lighting measures
- HVAC measures
- Developing calibrated models
- Developing LCC and ROI results for specific individual measures and combinations of measures.

Since the background work has already been done in developing this methodology and the parametric software tools, it will be easier and faster (less expensive) to develop future refinements.

5.3.10 References

1. ANSI/ASHRAE/IESNA Standard 90.1-2004. E*nergy Standard for Buildings Except Low-Rise Buildings*.

2. ANSI/ASHRAE/IESNA Standard 90.1-2010. *Energy Standard for Buildings Except Low-Rise Residential Buildings*.

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4. Building Control Virtual Building Test Bed, Lawrence Berkley National Lab, https://gaia.lbl.gov/bcvtb.

5. EnergyPlus Energy Simulation Software, Version 6.0, Updated October 18, 2010, DOE 2011, http://apps1.eere.energy.gov/buildings/energyplus.

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7. Thornton BA, W Wang, MD Lane, MI Rosenberg, and B Liu. 2009. Technical Support Document: 50% Energy Savings Design Technology Packages for Medium Office Buildings. PNNL-19004, Pacific Northwest National Laboratory, Richland, WA.

8. Thornton BA, W Wang, Y Huang, MD Lane, and B Liu. 2010. Technical Support Document: 50% Energy Savings for Small Office Buildings. PNNL-19341, Pacific Northwest National Laboratory, Richland, WA.

5.3.11 Appendices

EnergyPlus Simulation Analysis (See Appendix B)

5.4 Mechanical/HVAC Analysis

5.4.1 Introduction

The aim of this project is to establish benchmarks for building enclosure systems that are beyond the minimum levels often expressed in codes. The outcome is expected to provide guidance to the building owner in planning a set of Owner Performance Requirements (OPR) that will optimize the performance of the building enclosure and its interface with the heating, ventilating and air conditioning (HVAC) system for safety, security, energy, sustainability and economic performance.

The objective of the work described in this section of the Report was limited to evaluating and making recommendations regarding: 1) external releases of Chemical Biological and Radiological (CBR) agents; 2) transport of these agents across the building enclosure; and 3) three specific HVAC interactions with the enclosure: the effectiveness of filtering the make-up air intake; air pressurization control for perimeter zones; and sensing, monitoring and control functions related to CBR protection from external releases.

To meet this objective, the work was approached in three steps:

- Baseline and benchmark performance criteria and metrics were defined to evaluate:
    - CBR protection from external releases;
    - The impacts on energy utilization and the corresponding environmental footprint, and the percentages attributable to the building enclosure; and
    - Opportunities to apply renewable energy resources that do not produce greenhouse gases.
- Descriptions were provided for system characteristics that would comply with the baseline and benchmark performance criteria.
- Preliminary estimates of performance outcomes were developed from the baseline and benchmark criteria and the system characteristics for the nexus of CBR protection and energy utilization.

Owing to the complexities associated with CBR protection and the involvement of the HVAC systems in energy conservation and environmental footprint, the HVAC/Mechanical analysis is divided into two components: the Summary version, presented here, is supported by a more detailed discussion contained in a Detailed Mechanical Technical Analysis (Appendix C) with its accompanying Appendices C.1 – C.3.

The summary of the findings, conclusions and recommendations that are further expanded upon in the Detailed Analysis (attached as Appendix C) is given here in terms of preliminary predictions of outcomes, proposed validation and verification procedures, and a proposed outreach program.

5.4.2 High Performance Criteria

5.4.2.1 Attributes, Sub-attributes and Demands

Evaluation of CBR protection from external releases, its impacts on energy utilization and environmental footprint attributable to the building enclosure, and the opportunity to offset these impacts with renewable resources involved four of the attributes defined in EISA-2007. Sub-attributes have been defined within each of these attributes, as listed in Columns A and B of Appendix C.1, page 2 and summarized in Table 5-10:

Table 5-10: Attributes and Sub-Attributes for Evaluating CBR Protection and its Impact on Energy Use and Environmental Footprint

Attribute	Sub-attribute
Security	• CBR Protection from external releases of man-made hazards
Energy	• Thermal Loads resulting from sensible and latent heat transfer through the building enclosure. • Whole Building Energy Utilization rates from which percentages can be attributed to building enclosures.
Environment	• Environmental Footprint calculated from the whole building energy utilization rates and from which percentages can be attributed to building enclosures.
Sustainability	• Renewable Energy opportunities for alternative methods of energy production, which can be associated with building enclosures.

Expressions of demand or threat, which have been used to characterize the sub-attributes, are summarized in Table 5-11 here, associated system vulnerabilities and operational and resiliency performance impacts are described in more detail on pages 3 – 6 of the Detailed Analysis (Appendix C).

Table 5 11: Sub-attributes, Demands, Vulnerabilities and Resiliency for Evaluating CBR Protection and its Impact on Energy Use and Environmental Footprint

Sub-attribute	Demand	Vulnerability	Resiliency
CBR Protection	• Release Location: Remote, Onsite, and Proximate. • Threat Level: Low, Moderate, High. • Agent: Chemical, Biological or Radiological substances that are intentionally released to cause harm. • Exposure: the product of airborne concentration of the agent and the duration of release at its location.	Weakness of the enclosure and HVAC system to protect against exposure from the external CBR releases.	The impact on continuity of operations and/or shelter-in-place areas during and after an attack could range from minor to severe, in a few zones or throughout the whole facility.
Thermal Loads	• Enclosure Sensible and Latent Heat Gain and Loss Rates • Enclosure Thermal Loads • Enclosure Mass Transfer Rates	Weakness of the enclosure and HVAC system to minimize annual average sensible and latent enclosure loads and mass transfer rates during normal operations. .	The impact on continuity of operations (i.e., thermal control) could range from minor to severe, in a few zones or throughout the whole facility
Whole Building Energy Utilization	• Site-Energy Mix, Availability, Reliability and Redundancy • Site-Energy Costs and Demand Charges • Percentage of Whole Building Energy Utilization Attributable to the Building Enclosure	Weakness of the building enclosure and HVAC sub-systems to comply with the attributable percentage of whole building energy target for baseline or benchmark performance during normal operations.	Site energy availability, reliability and redundancy are critically important to continuity of operations and to the duration of lost operations.
Environmental Footprint	Equivalent CO_2 Emission (CO_2e)	Weakness of the building enclosure and HVAC sub-systems to comply with the attributable percentages of whole building energy and CO_2e targets for baseline or benchmark performance during normal operations.	Not Applicable
Renewable Energy (Opportunities)	• Onsite Energy Use • Onsite Energy Production	Weakness of the renewable energy sub-systems (i.e., solar PV) to comply with the expected off-sets in whole building energy targets for baseline and benchmark performance.	Onsite energy systems that are interfaced with the building enclosure could have either positive or negative impact on continuity of operations and duration of lost operations, dependent upon the performance (e.g., reliability, durability) of the renewable energy sub-systems during response and recovery times.

5.4.2.2 Baselines and Benchmarks

Baseline and benchmark criteria for the sub-attributes have been defined based on federal law and regulations,[18] published standards and guidance documents from federal agencies[19] and from nationally recognized non-governmental organizations:[20]

- Baseline criteria have been defined as measurable parameters and values for performance requirements that are consistent with existing building codes and nominal standards of care.
- Benchmark criteria have been defined as measureable parameters and values for performance requirements that provide for increased demands/threats, reduced vulnerabilities and increased resilience.

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18 ISA. 2007. Title IV: Energy Savings in Buildings and Industry. Energy Independence and Security Act of 2007. Public Law 110-140, December 19, 2007.

ISC. 2009. *Physical Security Criteria for Federal Facilities An Interagency Security Committee Standard*, December 1, 2009. For Official Use Only (FOUO). Department of Homeland Security, Washington, DC.

19 FEMA. 2003. R*eference Manual to Mitigate Potential Terrorist Attacks Against Buildings: Providing Protection to People and Buildings.* Risk Management Series 426. Federal Emergency Management Administration. Department of Homeland Security, Washington, DC.

NIOSH. 2002. *Guidance for Protecting Building Environments from Airborne Chemical, Biological, or Radiological Attacks.* DHHS (NIOSH) Publication No. 2002-139. National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention, Department of Health and Human Services, Cincinnati, OH, May 2002.

NIOSH. 2003. *Guidance for Filtration and Air-Cleaning Systems to Protect Building Environments from Airborne Chemical, Biological, or Radiological Attacks.* DHHS (NIOSH) Publication No. 2003-136. National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention, Department of Health and Human Services, Cincinnati, OH, April 2003.

DoD. 2007. *Unified Facilities Criteria (UFC): DoD Minimum Antiterrorism Standards for Buildings.* Department of Defense, UFC 4-010-01 8 October 2003 Including change 1, 22 January 2007, Washington, DC.

GSA. 2010. PBS P100-2010: *Facilities Standards for the Public Building Service.* November 2010, U.S. General Services Administration, Washington, DC.

20 ASHRAE. 2009. Guideline 29-2009: *Guideline for the Risk Management of Public Health and Safety in Buildings.* American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. Atlanta.

NRC. 2007. *Protecting Building Occupants and Operations from Biological and Chemical Airborne Threats.* National Research Council, National Academy of Sciences Press, Washington, DC.

ASHRAE. 2004. *Standard 90.1-2004: Energy Standard for Buildings except Low-Rise Residential Buildings.* American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., Atlanta. GA.

ASHRAE. 2010. *Standard 90.1-2010: Energy Standard for Buildings Except Low-Rise Residential Buildings.* American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., Atlanta. GA.

ASHRAE. 2011. A*dvanced Energy Design Guide for Small to Medium Office Buildings: Achieving 50% Energy Savings toward a Net Zero Energy Building,* May 2011, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., Atlan

SHRAE. 2010. *Standard 62.1-2010. Ventilation for Acceptable Indoor Air Quality.* American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., Atlanta. GA.

These criteria are described on pages 6 – 12 of the Detailed Analysis (Appendix C) and are summarized in Table 5-12 for each of the Sub-attributes for baseline performance and for three levels of enhanced performance (i.e., improved, P+; enhanced, P++; and Future/High Performance)

Table 5-12: Baseline and Benchmark Criteria for Sub-attributes

Sub-attribute	Level of Performance			
	Baseline	Improved (P+)	Enhanced (P++)	Future/High Performance
CBR Protection	Low-threat applications where high-vulnerability systems are acceptable.	Moderate-threat applications where high to moderate vulnerability systems are acceptable.	High-threat applications where moderate- to low-vulnerability systems are required.	Very High-threat applications where very low-vulnerability (i.e., very high-resistance) systems are required.
Whole Building Energy Utilization	The expected annual EUI and percentage attributable to the enclosure when the building is designed in compliance with ASHRAE Standard 90.1-2004.	The expected annual EUI and percentage attributable to the enclosure when the building is designed in compliance with ASHRAE Standard 90.1-2010 (i.e., 30% below ASHRAE Standard 90.1-2004).	The expected annual EUI and percentage attributable to the enclosure when the building is designed in compliance with the ASHRAE Advanced Energy Design Guide for Small to Medium Office Buildings†† (i.e., 50% below ASHRAE Standard 90.1-2004).	The expected annual EUI and percentage attributable to the enclosure when the building is designed in compliance with the goal to achieve zero-net-energy (ZNE).†
Environmental Footprint	The calculated value of CO_2e (i.e., in units of equivalent emissions of carbon dioxide) and percentage attributable to the enclosure when the building is designed in compliance with ASHRAE Standard 90.1-2004 and assumed fuel mix.	The calculated value of CO_2e and percentage attributable to the enclosure when the building is designed in compliance with ASHRAE Standard 90.1-2010 and assumed fuel mix.	The calculated value of CO_2e and percentage attributable to the enclosure when the building is designed in compliance with the ASHRAE Advanced Energy Design Guide†† and assumed fuel mix.	The calculated value of CO_2e and percentage attributable to the enclosure when the building is designed in compliance with goal to achieve ZNE.†
Renewable Energy (Opportunities)	The expected value of the photovoltaic (PV) plate area (SF) to GSF ratio for lighting and plug loads when the building is designed in compliance with ASHRAE Standard 90.1-2004.	The expected value of the PV plate area (SF) to GSF ratio for lighting and plug loads when the building is designed in compliance with ASHRAE Standard 90.1-2010.	The expected value of the PV plate area (SF) to GSF ratio for lighting and plug loads when the building is designed in compliance with the ASHRAE Advanced Energy Design Guide.††	The expected value of the PV-plate area (SF) to GSF ratio for all of the residual EUI when the building is designed in compliance with goal to achieve ZNE.†

† EISA. 2007. Title IV: Energy Savings in Buildings and Industry. Energy Independence and Security Act of 2007. Public Law 110-140, December 19, 2007.

†† ASHRAE. 2011. Advanced Energy Design Guide for Small to Medium Office Buildings: Achieving 50% Energy Savings toward a Net Zero Energy Building, May 2011, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., Atlanta. GA.

5.4.3 Systems for Meeting Demands/Resisting Threats

The objective of the mechanical analysis in Phase 1 has been to evaluate means and methods of reducing the risk of occupant exposure to externally released CBR agents that penetrate the building enclosure. This evaluation has focused on: 1) the interactions of building sub-systems that are capable of impeding the transport of these agents across the building enclosure and into occupied spaces; 2) the impacts of these sub-systems on energy utilization and carbon footprint attributable to the building enclosure; and 3) the opportunity to offset these impacts with roof-mounted photovoltaic arrays. The characteristics of the enclosure and HVAC subsystems that were used in this evaluation are described in Appendix C.

5.4.4 Estimates of Cost Impacts

PNNL studies[21] and the experiences of the Mechanical Committee members provide the basis for the preliminary estimates of the impacts that the interactions of the enclosure and HVAC sub-systems may have on first costs and maintenance and operational costs to provide for CBR protection and reduced energy consumption. The estimated values and the approach used in obtaining these estimates are summarized in Table 5-15, below in this section, and described in more detail in Appendix C.

5.4.5 Description of Interactions

The preliminary cost impacts of the interactions between the enclosure and HVAC sub-systems are described as discrete factors pertaining to two-way interactions involving four levels of CBR protection and four levels of energy utilization. A discussion of the anticipated functional and economic interactions between the enclosure sub-attributes and the HVAC sub-systems is provided in Appendix C.

5.4.6 Predictions of Outcomes

The following predictions of the performance of building enclosures, and their interactions with HVAC systems with regard to CBR protection from external releases, are based on a review of current practice and available information. In most cases, these predicted outcomes will require subsequent validation and verification.

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21 Thornton, B.A., Wang, W, Lane, M.D., Rosenberg, M.I., and Liu, B. 2009. *Technical Support Document: 50% Energy Savings Design Technology Packages for Medium Office Buildings*, September, 2009, Pacific Northwest National Laboratory, PNNL 19004, U. S. Department of Energy, Washington, DC.

Thornton, B.A., Wang, W, Huang, Y., Lane, M.D., and Liu, B. 2010. *Technical Support Document: 50% Energy Savings Design Technology Packages for Small Office Buildings,* April, 2010, Pacific Northwest National Laboratory, PNNL 19341, U. S. Department of Energy, Washington, DC.

5.4.6.1 CBR Protection with HVAC Interface

1. The building enclosure, which is often the first line of CBR protection against external releases, may also be one of the most vulnerable elements of a building due to its 1) air and water vapor infiltration; 2) fenestrations, such as operable windows, doors and other natural ventilation ports; and 3) the locations and treatment of the make-up air intakes for ventilation and pressurization. Also, the building enclosure may account for less than 5% of the whole building energy utilization in moderate climates but more than 30% in severe climates (see Table 5-14, below in this section and Appendix C.2 of the Full Analysis). However, these percentages can be changed by employing energy efficient technologies in other sub-assemblies to shift the energy balance within the building. This ability to shift the energy balance while maintaining the whole building energy target is very important when compensating for design changes to the enclosure to enhance resistance to blast, CBR, or other threats.

2. Quantitative criteria for exposures to airborne CBR agents are not available in the scientific or technical literature, nor are reliable low-cost CBR sensors, resulting in the practice of depending on passive performance and classifications of risks. This lack of quantitative exposure criteria increases the uncertainties of the vulnerability of the building enclosure and the risk to occupants and assets. A research project should be initiated to develop CBR exposure criteria and methods of low-cost measurement, in terms that are analogous to those for blast and that are understandable to the occupants and to the design teams who are responsible for optimizing the performance of the enclosure or the whole building.

3. In the absence of quantitative exposure criteria, qualitative criteria for level of risk (LOR) and level of protection (LOP) (i.e., Facility Security Levels FSL I to V)[22] have been identified and utilized in Phase 1:

   - The FSL categories have been used as the basis for characterizing:
     - The LOPs for CBR protection from external releases for various configurations of the enclosure and its interface with the HVAC sub-system;
     - The impacts of external releases and LOPs on energy utilization and corresponding environmental footprint, and the percentages attributable to the building enclosure; and
     - The opportunities to offset these impacts with renewable resources.

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22 ISC. 2009. *Physical Security Criteria for Federal Facilities An Interagency Security Committee Standard*, December 1, 2009. For Official Use Only (FOUO). Department of Homeland Security, Washington, DC.

- Baseline and three levels of benchmark (i.e., P+, P++, and Future/HP) performance criteria were defined on pages 6 – 8 in the full Detailed Analysis (Appendix C) and summarized in Table 5-12. They are consistent with the FSL categories and the other sub-attributes (e.g., energy utilization, blast, ballistics, seismic, flood, and wind forces) in the Phase 1 Project.

4. In lieu of direct control of exposure for CBR protection, indirect control through passive and active resistance is relied upon in practice. Two methods of passive control (i.e., resistance of air and moisture transfer through the building enclosure, and filtration of make-up air) and two methods of active control (i.e., air pressurization control of perimeter zones and sensing, monitoring and control strategies) are used to impede the transport of CBR agents and other outdoor air contaminants, across the building enclosure and into occupied spaces.

   - **Passive resistance** involves the integrity of the thermal and moisture transfer characteristics of the building enclosure, the air leakage through the make-up air dampers and the removal efficiencies of particulate and chemical filtration devices in the make-up air streams. The means and methods that improve thermal performance of the building enclosure also improve resistance to transport of externally released CBR agents across the enclosure.
   - **Active resistance**, as limited in Phase 1, involves pressurization control of perimeter zones by the make-up air component of the HVAC sub-system when fenestrations (i.e., windows, doors, natural ventilation ports) are closed, except for the FSL V category that requires detection (i.e., sensing) and control for suspected CBR agents.[23] Although their uncertainties are not well-defined or quantified, these methods are being required by ISC-200912 and recommended in other standards and guidelines.

Passive resistance involves the integrity of the thermal and moisture transfer characteristics of the building enclosure.

Active resistance, as limited in Phase 1, involves pressurization control of perimeter zones by the make-up air component of the HVAC sub-system.

23 ISC. 2009. *Physical Security Criteria for Federal Facilities An Interagency Security Committee Standard*, December 1, 2009. For Official Use Only (FOUO). Department of Homeland Security, Washington, DC.

These uncertainties are likely to be large as they depend not only on the design but also on the maintenance and operations by the facility staff and the motivation of the occupants.[24]

5. CBR protection also requires removal of the externally released agents, which have penetrated the building enclosure, by transporting them to centralized or local filtration systems within the building. HVAC interactions for removal of CBR agents that penetrate the building enclosure, and those that are released within the building, are dependent on the air distribution performance of the whole HVAC system, the analysis of which was outside the scope of Phase 1.The means and methods of transport and removal of CBR agents within buildings, which are critical for effective and timely CBR protection, should be evaluated and developed in subsequent Phases.

5.4.6.2 Energy Utilization and Production

1. Peak and partial thermal loads of enclosures, with or without blast resistance or CBR protection, do not directly translate to annual energy utilization rates. Therefore, inferential methods were required that consisted of defining energy targets from simulation and modeling, and attributing portions of them to building enclosures.

   Table 5-13 is a matrix that identifies the combinations of building enclosure and HVAC sub-systems, with and without the solar PV option, which are expected to comply with the identified combined levels of energy utilization and CBR protection performance criteria.

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24 ASHRAE. 2009. Guideline 29-2009: *Guideline for the Risk Management of Public Health and Safety in Buildings.* American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. Atlanta.

NRC. 2007. *Protecting Building Occupants and Operations from Biological and Chemical Airborne Threats.* National Research Council, National Academy of Sciences Press, Washington, DC.

FEMA. 2003. *Reference Manual to Mitigate Potential Terrorist Attacks Against Buildings: Providing Protection to People and Buildings.* Risk Management Series 426. Federal Emergency Management Administration. Department of Homeland Security, Washington, DC.

NIOSH. 2002. *Guidance for Protecting Building Environments from Airborne Chemical, Biological, or Radiological Attacks.* DHHS (NIOSH) Publication No. 2002-139. National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention, Department of Health and Human Services, Cincinnati, OH, May 2002.

NIOSH. 2003. *Guidance for Filtration and Air-Cleaning Systems to Protect Building Environments from Airborne Chemical, Biological, or Radiological Attacks.* DHHS (NIOSH) Publication No. 2003-136. National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention, Department of Health and Human Services, Cincinnati, OH, April 2003.

DoD. 2007. *Unified Facilities Criteria (UFC): DoD Minimum Antiterrorism Standards for Buildings.* Department of Defense, UFC 4-010-01 8 October 2003 Including change 1, 22 January 2007, Washington, DC.

As examples: Combination #1 represents an enclosure/HVAC subsystem that does not have the PV option, and is intended to provide Baseline Energy/Environment performance and Baseline CBR Protection; Combination #7a represents an enclosure/HVAC subsystem that provides the PV option, and is intended to provide a P+ level of Energy/Environment performance and a P++ level of CBR Protection.

- The **bold numbers** with green background (across the top row) identify sub-systems (i.e., 1, 5, 9 and 13 without optional PV arrays and 1a, 5a, 9a, and 13a with optional PV arrays), at baseline level CBR protection for which performance outcomes are estimated in Appendix C.2. These sub-systems are described in Appendix C in the sub-section of Metrics and Outcomes.
- The ***bold-italicized numbers*** with red background (down the diagonal) identify the integrated sub-systems (i.e., 1, 6, 11 and 16 without optional PV arrays and 1a, 6a, 11a, and 16a with optional PV arrays) for which compliance is expected with all of the criteria for the indicated level of performance, as described in the section on Description of System Characteristics in the Detailed Analysis.
- All other sub-systems in the matrix depend on additional modeling and simulations, as described for reducing CBR vulnerabilities in the Expected Outcomes sub-section of Metrics and Outcomes, which are outside the scope of Phase 1.

Table 5-13: Matrix of Enclosure and HVAC Sub-systems at each Performance Level for CBR Protection and Energy/Environmental Performance, with and without Optional Solar PV Sub-systems

Level of Performance Energy/Environment → CBR Protection ↓	Baseline		P+		P++		Future/HP	
	No PV	Optional PV	No PV	Optional PV	No PV	Optional PV	No PV	Optional PV
Baseline	**1** ***1***	**1a** ***1a***	**5**	**5a**	**9**	**9a**	**13**	**13a**
P+	2	2a	***6***	***6a***	10	10a	14	14a
P++	3	3a	7	7a	***11***	***11a***	15	15a
Future/HP	4	4a	8	8a	12	12a	***16***	***16a***

2. Baseline and benchmark targets for whole building energy utilization intensity (EUI), and corresponding environmental footprint values (i.e., equivalent carbon dioxide emission rates – CO_2e), have been defined in detail on pages 9 – 11 in Appendix C Detailed Analysis at minimum/low levels of CBR protection (i.e., FSL I/II systems 1, 5, 9, and 13 in Table 5-13) for compliance with values that are consistent with federal law and regulations.[25] Table 5-14 summarizes expected ranges across climatic zones, and their percentages attributable to the opaque and glazed surface areas of the enclosure.

Table 5-14: Expected Ranges Across Climatic Zones of EUI Targets and Corresponding CO_2e Values, and Percentages Attributable to the Opaque and Glazed Surface Areas of the Building Enclosure at Minimum/Low Level of CBR Protection (FSL I/II)

Level of Energy Performance	System (from Table 5-13)	Energy Utilization Intensity (EUI)		Environmental Footprint (CO_2e)	
		kBtu/GSF/yr	% to Enclosure	Lb/GSF/yr	% to Enclosure
Baseline	1	46-70	4-23	9-25	<1-6
P+	5	31-43	1-24	6-15	<1-3
P++	9	22-31	6-30	4-11	<1-3
Future/HP	13	20-29	6-30	3-10	<1-3

The EUI targets are as much as 5 times lower than the average energy consumption rates in the CBECS database and the validated EUIs from 19 office buildings.[26]

These EUI target values are presumed to provide for acceptable indoor environmental quality and occupant performance, but evidence exists that this presumption may not be valid.[26]

These comparisons reveal the challenge ahead in achieving, validating and verifying simultaneous energy reduction and CBR protection at the combined benchmark performance levels (P+, P++, and Future/HP), shown in Table 5-13 as sub-systems 6, 11 and 16.

25 EISA. 2007. Title IV: Energy Savings in Buildings and Industry. Energy Independence and Security Act of 2007. Public Law 110-140, December 19, 2007.

ISC. 2009. *Physical Security Criteria for Federal Facilities An Interagency Security Committee Standard*, December 1, 2009. For Official Use Only (FOUO). Department of Homeland Security, Washington, DC.

26 Woods, J.E., Sweetser, R., and Novosel, D. 2009. Task 06-02: Scientific Outreach Program Pilot. Final Report NCEMBT-090717 to U.S. Department of Energy under cooperative agreement DE-FC26-03GO13072, July 2009, National Center for Energy Management and Building Technologies, Alexandria, VA.

3. Benchmark targets for EUI and corresponding CO_2e values will likely be higher than the baseline targets at each incremental increase of CBR protection level. However, Phase 1 does not include estimates for the EUI target values and corresponding CO_2e values for these combinations of CBR protection and energy performance. These adjusted benchmark targets should be determined in subsequent phases. The uncertainties of the outputs for these combinations are high and should be minimized through energy modeling, after the changes in enclosure characteristics, filtration and control strategies have been included in the model.

4. The energy production targets and PV plate area to GSF ratios indicate that the roof-mounted PV options may be applicable for one or two-story buildings, but their capacities are problematic for taller buildings:

   - Although the application of these options provides the capability of offsetting the consumption of fossil fuels to meet part or all of the EUI requirements, they do not reduce the required capacities or schedules of operations of the HVAC sub-systems.
   - The estimated PV-plate area (SF) to GSF ratios needed to offset all of the residual EUIs for a zero-net-energy (ZNE) building[27] are 50-100 percent larger than the ratios needed to offset the lighting and plug loads in the P++ category.
   - Reliable benchmark performance of the HVAC sub-systems for CBR protection requires the use of redundant energy resources.

   These findings reveal a potential conflict with the concept of ZNE, which requires that, if cost-effective, the residual EUI be met with renewable resources that do not produce greenhouse gases.[25]

5.4.6.3 Economic Performance

1. Based on the PNNL studies,[28] the first cost of the modeled building at baseline performance with ASHRAE Standard 90.1-2004[29] (i.e., system 1 in Table 5-13) would range from \$93 – \$155/GSF for a 1-4 story office building in the 17 climatic zones.

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27 EISA. 2007. Title IV: Energy Savings in Buildings and Industry. Energy Independence and Security Act of 2007. Public Law 110-140, December 19, 2007.

28 Thornton, B.A., Wang, W, Lane, M.D., Rosenberg, M.I., and Liu, B. 2009. *Technical Support Document: 50% Energy Savings Design Technology Packages for Medium Office Buildings,* September, 2009, Pacific Northwest National Laboratory, PNNL 19004, U. S. Department of Energy, Washington, DC.

. Thornton, B.A., Wang, W, Huang, Y., Lane, M.D., and Liu, B. 2010. *Technical Support Document: 50% Energy Savings Design Technology Packages for Small Office Buildings*, April, 2010, Pacific Northwest National Laboratory, PNNL 19341, U. S. Department of Energy, Washington, DC.

29 ASHRAE. 2004. *Standard 90.1-2004: Energy Standard for Buildings except Low-Rise Residential Buildings*. American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., Atlanta. GA.

However, experience reveals that actual Class A and monumental buildings can have first costs that exceed this range by factors of two or more.

- The estimated incremental first costs of the modeled building in compliance with ASHRAE 50% AEDG[30] and at minimum/low CBR protection (i.e., system 9 in Table 5-13), as compared to the building at baseline energy performance (i.e., system 1), were reported to range from \$2.37 – \$4.22/GSF.[31] This represents 1.5 – 4.5% of the estimated first costs for the modeled building. These low incremental first costs were rationalized to be the result of reduced internal and enclosure loads, and higher energy efficiency of HVAC components including a dedicated outdoor air ventilation system (DOAVS) with energy recovery. The incremental first costs of the modeled building for compliance with ZNE requirements (i.e., systems 13 and 13a in Table 5-13) have not been estimated in Phase 1. These incremental first cost estimates should be validated and verified in subsequent Phases.

2. Annual whole building energy costs were not reported in the PNNL studies[32] but experience reveals that they range from approximately \$1.50/GSF to more than \$5.00/GSF for commercial buildings in the U.S.

   - Based on the PNNL studies, annual energy cost savings for a P++ energy performance with baseline CBR protection (FSL I/II) (i.e., system 9 in Table 5-13) when compared to baseline energy and CBR performance (i.e., system 1 in Table 5-13) may range from \$0.65 – \$0.89/GSF, which represents a 13 – 59% energy cost savings compared to the expected energy costs for system 1 in Table 5-13. The PNNL studies did not address what percentage of estimated energy savings was attributable to the building enclosure.

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30 ASHRAE. 2011. *Advanced Energy Design Guide for Small to Medium Office Buildings: Achieving 50% Energy Savings toward a Net Zero Energy Building,* May 2011, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., Atlanta. GA..

31 Thornton, B.A., Wang, W, Lane, M.D., Rosenberg, M.I., and Liu, B. 2009. T*echnical Support Document: 50% Energy Savings Design Technology Packages for Medium Office Buildings,* September, 2009, Pacific Northwest National Laboratory, PNNL 19004, U. S. Department of Energy, Washington, DC.

. Thornton, B.A., Wang, W, Huang, Y., Lane, M.D., and Liu, B. 2010. T*echnical Support Document: 50% Energy Savings Design Technology Packages for Small Office Buildings*, April, 2010, Pacific Northwest National Laboratory, PNNL 19341, U. S. Department of Energy, Washington, DC.

32 Thornton, B.A., Wang, W, Lane, M.D., Rosenberg, M.I., and Liu, B. 2009. *Technical Support Document: 50% Energy Savings Design Technology Packages for Medium Office Buildings*, September, 2009, Pacific Northwest National Laboratory, PNNL 19004, U. S. Department of Energy, Washington, DC.

Thornton, B.A., Wang, W, Huang, Y., Lane, M.D., and Liu, B. 2010. *Technical Support Document: 50% Energy Savings Design Technology Packages for Small Office Buildings*, April, 2010, Pacific Northwest National Laboratory, PNNL 19341, U. S. Department of Energy, Washington, DC.

PNNL estimated that these energy savings would yield simple paybacks ranging from 3.3 to 6.2 years for the VAV option, and 5.6 to 11.5 years for radiant heating and cooling options.

Additional energy cost savings are potentially available for the Future/HP energy performance with baseline CBR protection, but have not been estimated in Phase 1.Subsequent phases should include a validation and verification of the estimates of incremental energy cost savings and expenditures for the building and those attributable to the building enclosure. Moreover, the corresponding simple payback times should be re-evaluated using benefit-risk/LCC models described below.

3. The PNNL studies did not provide estimates of maintenance and operational costs. Experience reveals that annual maintenance and operational costs for baseline energy performance and CBR protection (i.e., system 1 in Table 5-13 and Table 5-14) may range from $2.00 – $4.00/GSF for commercial buildings in the U.S.

   - Phase 1 did not include an investigation of the incremental maintenance and operational cost expenditures for increased CBR protection that are attributable to the building enclosures. Issues include the effects on housekeeping due to open windows (e.g., natural ventilation), cleaning of exterior and interior building enclosure surfaces and maintenance of PV sub-systems. These estimates of maintenance and operation should be developed, validated, and verified in subsequent phases.

Table 5-15 is a summary of estimated costs for the modeled whole building, based on the preliminary findings.

Table 5-15: Estimated Costs ($/GSF) for the Building Modeled by PNNL (See References 25 and 26 in Section 5.4.9)

	Estimated Costs in $/GSF for the PNNL Modeled Building			
Performance Level	**Baseline**	**P+**	**P++**	**HP/F**
First Cost w/o PV option				
Baseline CBR*	93 – 155	NA	+2.37-4.22	NA
Increasing CBR LOP at Baseline EUI	93 – 155	+2.50-5.00	+6.00-11.00	+7.00-13.00
Annual Energy Cost w/o PV option				
Baseline CBR*	1.50-5.00	NA	+0.65-0.89	NA
Increasing CBR LOP at Baseline EUI	1.50-5.00	+0.50-1.00	+0.50-1.00	+1.00-2.00
Annual Maintenance and Operating Cost w/o PV option				
Baseline CBR	2.00-4.00	NA	NA	NA
Increasing CBR LOP at Baseline EUI	2.00-4.00	+0.50-1.00	+0.50-1.00	+2.00-3.00

* Thornton, B.A., Wang, W, Lane, M.D., Rosenberg, M.I., and Liu, B. 2009. *Technical Support Document: 50% Energy Savings Design Technology Packages for Medium Office Buildings*, September, 2009, Pacific Northwest National Laboratory, PNNL 19004, U. S. Department of Energy, Washington, DC.

Thornton, B.A., Wang, W, Huang, Y., Lane, M.D., and Liu, B. 2010. *Technical Support Document: 50% Energy Savings Design Technology Packages for Small Office Buildings*, April, 2010, Pacific Northwest National Laboratory, PNNL 19341, U. S. Department of Energy, Washington, DC.

4. The definitions of high-performance buildings (HBP) and life-cycle cost (LCC) in EISA-2007[33] require the use of an LCC model that optimizes the cost-effectiveness of all of the HPB attributes being considered for a project.

    - Energy-based LCC analyses[34] provide systematic methods for comparing energy-related alternatives with different streams of costs *that assume all other benefits and risks are constant over the defined period*. This type of LCC analysis, without an integrated risk-benefit analysis, is incomplete and may be misleading, as it assumes no differences in risks or benefits between options under consideration.

    - Risk-benefit methods utilize LCC results to optimize alternatives, based on broad economic foundations. These methods account for first costs, energy costs, and other maintenance and operating costs, in conjunction with the economic benefit values for the attributes and sub-attributes in a HPB and the risks associated with CBR or other threats.[35] Risk-benefit analyses that incorporate LCC provide more comprehensive and accurate evaluations of alternatives to achieve compliance with the set of criteria for the attributes and sub-attributes that pertain to a project during the planning and design phases.

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33 EISA. 2007. *Title IV: Energy Savings in Buildings and Industry.* Energy Independence and Security Act of 2007. Public Law 110-140, December 19, 2007.

34 ASHRAE. 2004. *Standard 90.1-2004: Energy Standard for Buildings except Low-Rise Residential Buildings.* American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., Atlanta. GA.

ASHRAE. 2010. *Standard 90.1-2010: Energy Standard for Buildings Except Low-Rise Residential Buildings.* American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., Atlanta. GA.

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Chapman, R.E. 2003. *Applications of Life-Cycle Cost Analysis to Homeland Security Issues in Constructed Facilities: A Case Study.* NISTIR 7025, National Institute of Standards and Technology, Gaithersburg, MD.

5. An LCC model that optimizes the cost-effectiveness of all of the HPB attributes being considered for a project does not apparently exist. In a subsequent phase, an LCC program with risk-benefit analysis[36] should be interfaced with programs that provide contaminant analysis[37] for external and internal releases, and energy analysis.[38] Subsequently, the LCC/risk-benefit model should also be interfaced with programs for other sub-attributes (e.g., blast, ballistics, fire, wind, flood) that provide input data to the energy, contamination, and LCC/risk-benefit programs. When calibrated, this resultant model should be used to validate, verify, and/or revise the preliminary predictions.

5.4.7 Proposed Validation and Verification Procedures

The functional and economic interactions of all of the other attributes and sub-attributes will affect the nexus of CBR protection and EUI. To reduce the uncertainties discovered during the development of the preliminary estimates of outcomes in Phase 1, the following two-step process of validation and verification is recommended for subsequent phases of the project:

1. Step 1: Testing and modeling to validate the predicted results for CBR penetration of the building enclosures and the energy and economic impacts of reducing the penetration.

   - In lieu of actual CBR agents, initial validation procedures would use normal outdoor air contaminants as surrogates (e.g., water vapor, volatile organic compounds, bio-aerosols and radon) for which references to procedures and quantitative data are available. These procedures are described on page 41 in the Appendix C.
   - A standardized protocol would be developed for collection and analysis of the physical and cost data. This protocol would be analogous to those for blast, ballistic, wind and fire protection analyses.

36 Chapman, R.E. 2003. *Applications of Life-Cycle Cost Analysis to Homeland Security Issues in Constructed Facilities: A Case Study*. NISTIR 7025, National Institute of Standards and Technology, Gaithersburg, MD.

37 NIST. 2011. CONTAM 3.0. Multi-zone Airflow and Contaminant Transport Analysis Software, National Institute of Standards and Technology, Gaithersburg, MD., 11 January 2011, http://www.bfrl.nist.gov/IAQanalysis/index.htm. (Accessed 24 May 2011.)

38 DOE. 2011. EnergyPlus Energy Simulation Software. 5 April 2011, http://apps1.eere.energy.gov/buildings/energyplus. (Accessed 24 May 2011.)

- Based on the data from laboratory and field testing, and the building and HVAC characteristics, a calibrated simulation model would be used to validate the predicted values for:
  - ❑ The distribution effectiveness of the contaminants from the building enclosure to the controlled devices for removal.[39]
  - ❑ The whole building energy utilization (EUI) and corresponding environmental footprint (CO_2e).
  - ❑ The percentages of EUI and CO_2e attributable to the enclosure.
  - ❑ The results of the benefit-risk/LCC analysis.

2. **Step 2:** Verification to compare the results from the predicted and validated performance outcomes of site-specific buildings, being planned or designed, with their actual performance outcomes during the construction and operational phases (i.e., cases and controls).

- For technical and economic credibility, data verification cases would be determined by an experimental design in which statistically significant results can be expected from a set of case/control buildings.
- A standardized protocol for collection and analysis of the data would be developed to assure valid and reliable results. This protocol would be analogous to those for blast, ballistic, wind and fire protection.
- The verification process would be submitted for peer review and publication.

Based on the plans to obtain preliminary predictions, validations and verifications, an outreach/educational program should be developed and implemented that focuses on scientific, technical, economic, and practical means and methods to improve HPB design and operations for safety, health, security, efficient energy utilization, and cost-effectiveness.

5.4.8 Conclusions and Recommendations

Based on the findings in Phase 1, conclusions and recommendations from the Mechanical Analysis are:

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39 Woods, J. E. and Krafthefer, B. C. 1986. *Filtration as a Method for Air Quality Control in Occupied Spaces, Fluid Filtration: Gas*, Volume I, ASTM STP 975, R. R. Raber, Ed.; American Society for Testing and Materials, Philadelphia.

1. Synergies exist in the technologies to improve energy utilization in buildings and CBR protection from external releases. Methods that increase air and moisture tightness, and thermal resistance will also increase resistance to the transport of CBR agents and other contaminants across the enclosure, reduce building energy consumption and improve indoor environmental quality (i.e., thermal, air quality, acoustics and possibly lighting). Also, make-up air systems that incorporate dedicated outdoor air ventilation systems (DOAVS) with energy recovery components and high efficiency filtration will impede transport of the externally released CBR agents and other contaminants, reduce building energy consumption, and improve indoor air quality.

2. Strategies to achieve CBR Protection and Energy Security over time are compatible and can be optimized. CBR protection from external releases requires vigilance in detection and rapid response to an occurrence, which may persist over a period of minutes (e.g., chemical exposure) to days or weeks (e.g., biological or radiological exposure). Energy security requires vigilance in effective use of energy resources throughout the life-time of the building. Building energy utilization intensity (EUI) during periods of duress will be higher than during normal periods. Although building system capacities must be sufficient to provide the required level of protection (LOP) for periods of duress, control strategies can be established so that the likely long-term impact is minimal for compliance with defined annual EUI benchmark criteria. Conversely, control strategies can be established for the system to operate continuously at an enhanced benchmark level of CBR protection, which may result in a long-term increase in EUI. System optimization is also feasible that would improve long-term indoor environmental quality at reduced EUI and provide the expected LOP from undetected CBR releases.

3. Benefit-risk models that incorporate life-cycle cost analysis should be the basis for economic evaluations. Owner Performance Requirements should be based on dynamic modeling that integrates technical input from contamination and energy simulations with risk and benefit analyses over the life cycle of the building. Economic models that are currently being used in practice are limited to life-cycle cost analysis that focuses on energy costs and assume constant values for other risks and benefits. Planning and design decisions, which are based on these limited models, are likely to suppress the economic benefits of improved indoor environmental quality or the economic risks of inadequate CBR protection.

4. CBR Protection requires removal control within the building. The Phase 1 project was limited to evaluating methods of resisting external releases of airborne agents from penetrating the building

enclosure. However, those agents that do penetrate into the occupied spaces, and agents that are released within the building, must be removed by transporting them by air distribution in return air plenums or ductwork to air filtration equipment that is located centrally within the HVAC sub-systems or is located remotely (e.g., fan-filter modules) throughout the building. These methods of removal control will have significant effects on occupant exposure, building energy utilization, and economic benefits and risks.

5. Subsequent phases of the project should validate and verify the findings and the predicted outcomes from Phase 1. Subsequent phases should also extend the scope of CBR protection to include evaluation of internal releases and the effectiveness of removal control of these agents, including the impacts on occupant exposure, building energy utilization, and the short-term and long-term economic benefits and risks.

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5.4.10 Appendices

Appendix C: Detailed Mechanical Technical Analysis

Appendix C.1: HPBDE-Attributes-Metrics-Benchmarks-Outcomes

Appendix C.2: Combined Tables

Appendix C.3: Calculations for CO_2e and PV Power

6

OPR Model Algorithms and Decision-Making Methodologies

6.1 Introduction

This chapter provides an in depth explanation of the algorithms and decision-making methodologies employed to calculate and enable comparison of the attribute performance levels identified in the technical performance analysis section. It offers a more advanced understanding of the logic employed and steps followed to use the building performance data to generate levels of performance and to predict outcomes.

6.2 Demand Performance Relationship

The OPR model establishes performance outcomes at varying demand levels for a set of building parameters. The performances $\boldsymbol{P}$ and the demands $\boldsymbol{D}$ can be related through the function $\boldsymbol{g}(\,)$ as

$$\boldsymbol{P} = \boldsymbol{g}(\boldsymbol{S}, \boldsymbol{D})$$

Equation

The building description is contained in the parameter ***S***. Since the OPR delineates both ***P*** and ***D***, the solution of equation 1 is through a complex optimization process, and since ***S*** is constant for any given scenario, then the resulting performance $\tilde{\boldsymbol{P}}$ will be close, but not identical to the initial specified ***P***. The differences between ***P*** the specified and the resulting $\tilde{\boldsymbol{P}}$ depend on how realistic (and how compatible with ***S***) the specified demands ***D*** are. As mentioned earlier, equation 1 can be repeated several times to study different demand performance scenario pairs ($\tilde{\boldsymbol{P}}_i, \boldsymbol{D}_i$) with ***i*** indicating the scenario number. The user then can compare all the scenarios and choose the optimal scenario conditions.

The description of the building ***S*** is done through a set of inputs made by the user and predictions about behavior that were made by the technical team and are captured in the OPR model database. These predictions are multi-dimensional constants that relate all pertinent demand metrics and levels, to all performance metrics and levels. Description of the predictions, ***S***, is given in the next section.

6.3 Cost Outcomes

The OPR Model is based on the theory that the outcomes impacting the owner can be predicted by performance goals that are based on customary practices of design and construction without knowing the composition of actual or prospective building design and construction systems. Using multiple parameters to establish the facility needs, demands, and performance benchmarks, predictions can be made within a range of variation. At the early planning level there are three major categories of predictions:

1. **Capital Expense –** cost to procure and install a system
2. **Operating Expense –** cost to operate a system
3. **Re-Capitalization Expense –** cost to maintain or replace a system. Recapitalization has two parts:
    a. Due to normal operational wear and obsolescence
    b. Due to a safety (natural) or security (man-made) event

For each of these, the OPR Tool's underlying database includes estimated unit cost values to deliver baseline performance for the enclosure systems evaluated. The costs were developed during the technical analysis by utilizing the expertise of the technical teams as well as researching cost from the R.S. Means cost data publications. The database also includes default values for typical building dimension and configuration relationships from which key building measurement quantities are computed based on the limited information about the building available at the early planning phase and captured from the general project information input to the OPR Tool. These input values, plus the default values describing the building (many of which can be over-written by the user) are submitted to algorithms that, using the cost components identified above, compute the total cost of ownership and other metrics such as energy consumption.

The OPR Model is based on the theory that the outcomes impacting the owner can be predicted by performance goals that are based on customary practices of design and construction without knowing the composition of actual or prospective building design and construction systems.

Predictions are also made for the unit values to upgrade from the baseline to higher performance benchmarks based on the relative value of the baseline. These predictions are expressed in terms of a percentage of the baseline. In this way, the relationship to the baseline remains relatively constant once established and any changes in underlying values can be driven from the baseline.

Values for the Annual Operating Costs are also predicted as a percentage of the Capital Expense associated with a particular sub-attribute at each benchmark level. This result is also, the Return on Investment, in the case of the Net Energy sub-attributes, for upgrading from the baseline to each performance benchmark.

Predictions can come from several sources including an analysis of test systems, from mining values out of actual projects, from studies, and/or from "value judgments" by experts in the design, construction and performance of the particular building systems. Any or all of the above prediction approaches are an acceptable starting point however; different validation and calibration methods (described in Chapter 7) will need to be applied depending on which approach is employed to ensure their initial accuracy and ongoing validity. In this phase of the project, studies from published materials (identified in References throughout this report) and expert "value judgments" are the methodologies employed.

6.4 Interactions

Building systems are very complex and they coexist within the confines of the building space. Because of this condition, it is reasonable to make the observation that the behavior of some systems can affect the behavior of the building as it responds to multiple demands. So, it is reasonable to assume, for example, that a robust enclosure would have a positive effect on resisting both blast and wind pressures. In other words, the strong connection needed between the enclosure and the structural system to resist blast pressure will affect the behavior of the building in being energy efficient and resisting CBR threats as well. This illustrates that there is an inherent interaction between demands and system performance that affects the building behavior and response for the EISA attributes studied. In other words, a decision regarding energy efficiency might have a major effect on the robustness of the building during a CBR event.

Until now, such building system interactions have not been considered in any decision-making process in prescriptive or performance-based building designs. Ignoring such interactions can lead to erroneous performance estimates. This project accommodates interactions between all the demand and system metrics using the following process:

1. For a given metric $\boldsymbol{i}$ (say energy costs) and a given metric $\boldsymbol{j}$ (e.g. CBR robustness) with $\boldsymbol{i \neq j}$, estimate the effects of a decision concerning metric $\boldsymbol{i}$ on the behavior of the metric $\boldsymbol{j}$. This estimate is in the range of +/-100%. A + value means the two metrics would enhance each other's performance, and a – value would mean that the two metrics would have behavioral conflict.

2. Repeat the process between $\boldsymbol{i}$ and $\boldsymbol{j}$ in the reverse order. For a given metric $\boldsymbol{j}$ (e.g. CBR robustness) and a given metric $\boldsymbol{i}$ (e.g. energy costs) with $\boldsymbol{i \neq j}$, estimate the effects of a decision concerning metric $\boldsymbol{j}$ on the behavior of the metric $\boldsymbol{i}$. Note that the results of step 1 and 2 need not be identical.

3. Repeat steps 1 and 2 for all the pairings between all the performance, demand and system metrics in the OPR model.

This resulting interaction matrix populated with interaction predictions from the technical experts is contained in the OPR model database and used by the tool when calculating output performance levels. The interaction matrix is used to modify the independent prediction matrix (developed as described in the Predictions section) so as to arrive at output performances that account for the interactions between the different system and demand metrics of the project under consideration. This approach is based on the theory of multi-hazards (Ettouney et al 2005).

6.5 Uncertainties

The OPR model and tool consist of many components and employ numerous factors to inter-relate them, as illustrated in Figure 3-4 OPR Model processes. Obviously, there are inherent uncertainties in both the parametrics (and resulting values) for these factors and the process itself is both random and uncertain. Because of this, the OPR Tool is designed to be probabilistic at all levels. The uncertainties in the process are addressed by assuming that the predictions and interaction parameters, which constitute the components of $\boldsymbol{S}$ (building parameters as defined earlier) are random values. As such, each of the components of $\boldsymbol{S}$ (including both predictions and interactions) is defined by the following three values:

A. An average (mean)
B. An upper limit
C. A lower limit

Thus the probability distribution function of $\boldsymbol{S}$ is assumed to be truncated, with upper and lower limits. Since the components of $\boldsymbol{S}$ are uncertain, each of the components of the output performance, $\tilde{\boldsymbol{P}}$, will also be composed of three values:

D. An average (mean)
E. An upper limit
F. A lower limit

As a result, the OPR displays and reports will include the range of each of the output parameters. This range allows for the uncertainties inherent in the predictions process and could be used in performing additional statistical studies, if needed. See Benjamin and Cornell, 1970, for additional information.

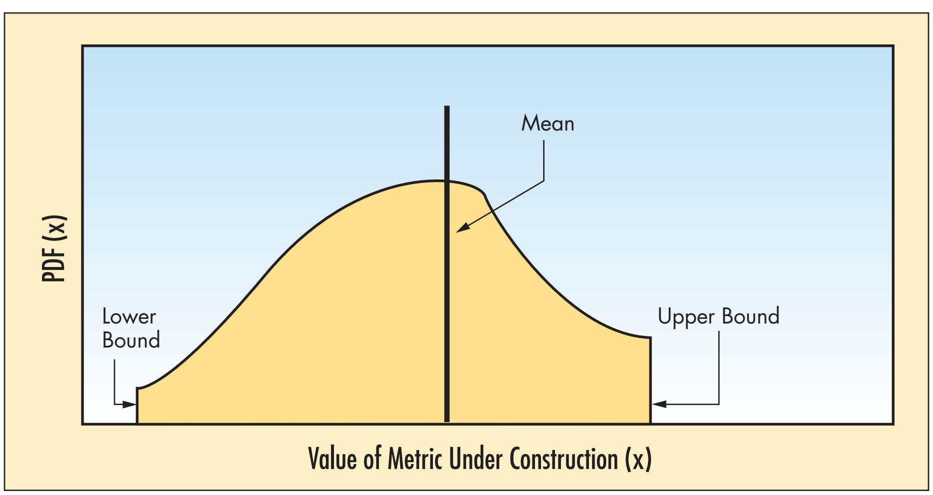

Figure 6-1: Ranges of Uncertainty

6.6 Analyzing Performance

To give a simple yet powerful structure to the decision-making process for the owner, the OPR model aggregates sub-attributes into three project level performance groups, Operational, Risk and Resilience for analysis of related demands and performances. These groupings allow for the setting of comprehensive project goals that can then be evaluated and refined to reach the best combination of attribute performance while providing a simple comparative framework for evaluation. Chapter 4 identifies how these are selected when using the OPR Tool. The following discussion provides the underlying reasoning behind how the project performance benchmarks work and how they are used to streamline the process of establishing performance targets for the project

6.6.1 Operational Performance

For project planning purposes, the OPR Tool provides the owner the ability to balance or optimize the estimated operational performance of the enclosure systems for a proposed facility based on their best interests. Owners that are more concerned about the capital cost may select a different composite of performance standards than those whose interest are in environment, operating costs, or total cost of ownership, for example.

The OPR Tool provides the owner the ability to balance or optimize the estimated operational performance of the enclosure systems for a proposed facility based on their best interests.

The OPR Tool incorporates rules that identify the degree of opportunity that exists based on the climate at any given location in the United States. Solar PV, for example will be emphasized in hot, dry climates, both in the scope and in the return on investment; whereas natural ventilation will be excluded in wet climates.

The common denominator that underlies all operational attributes — both in the Energy and the Durability categories — is Return on Investment (ROI) to analyze the performance of a facility. Not only is ROI a common and effective denominator that can work with both energy and durability, but ROI also incorporates the important EISA attribute of Cost-Benefit.

To simplify and streamline analysis, and owing to the inherent connections between certain related EISA attributes, Operational performance is evaluated in three attribute groupings:

1. **Energy** –The sub-attributes analyzed in this version of the OPR Tool that impact energy consumption include: thermal transfer, air leakage/tightness, daylighting and natural ventilation. Solar shading was not included as a separate sub-attribute in this version though it is incorporated in the Fenestration options employed to attain the HP performance level. As stated in Chapter 3, the current energy baseline has been established according to the ASHRAE 90.1 2004 standard with three increasingly higher benchmarks; Improved, Enhanced and High Performance, compared to this baseline.
2. **Durability** – Longer service life is the principle outcome of a more durable facility. In the OPR model, service life is a function of quality level identified for the building. Quality and service life relationships are discussed in the architectural section of this chapter and listed in Appendix A.1 to this report, the Performance Summary – Facility Operations Table. The way to achieve a more durable building enclosure is through the performance of two related sub-attributes – water penetration and moisture migration. In the OPR model, all three sub-attributes (service life, water penetration and moisture migration) are bundled together in the performance benchmark selections for Improved, Enhanced and High Operational Performance. Goals for each sub-attribute are established independently, first based on the level of Operational Performance selected and can then be adjusted by the user if desired. The three sub-attributes vary dependently however so that a higher or lower choice for any one results in a corresponding change in durability performance.
3. **Environment** — Environmental performance is established through the environmental footprint and acoustic isolation. The energy and durability attribute groups both contribute to the Environment attribute's performance. However, in this version of the OPR Tool, only the energy usage converted to its CO_2 equivalent (carbon footprint) is included. In future versions, the benefits of a more durable facility that requires far less demolition and reconstruction will also be incorporated.

The other sub-attribute under the environment attribute is acoustic isolation. Although acoustic isolation is included under the Operational performance category, its interactions are more closely tied with Resilience as a more resilient facility will also have greater acoustic resistant characteristics. Acoustic isolation performance at the benchmarks established is covered in the architectural section of this chapter and summarized in Appendix A.1 Facility Operations Performance.

6.6.2 Risk

Risk is a powerful decision-making tool that is employed in the OPR model to help choose the most efficient building configuration. Utilization of risk as a decision-making tool has been discussed by many authors. See for example references Ettouney, et al (2005), and Ettouney and Alampalli (2012a, 2012b).

The risk evaluations in the OPR Model are based on the equation:

Equation

$$\boldsymbol{R} = \boldsymbol{f}\ (\ \boldsymbol{T} \bullet \boldsymbol{V} \bullet \boldsymbol{C}\ )$$

The function $\boldsymbol{f}$ ( ) is a complex nonlinear function that accommodates potential interactions between $\boldsymbol{T}$, $\boldsymbol{V}$, and $\boldsymbol{C}$, and where the hazard (threat) is expressed by $\boldsymbol{T}$, the vulnerability of the asset is expressed by $\boldsymbol{V}$, while the consequences of the event is expressed by $\boldsymbol{C}$. This risk expression has been used in FEMA 455, and DHS (2009, 2009a, 2009b, 2009c, and 2009d)

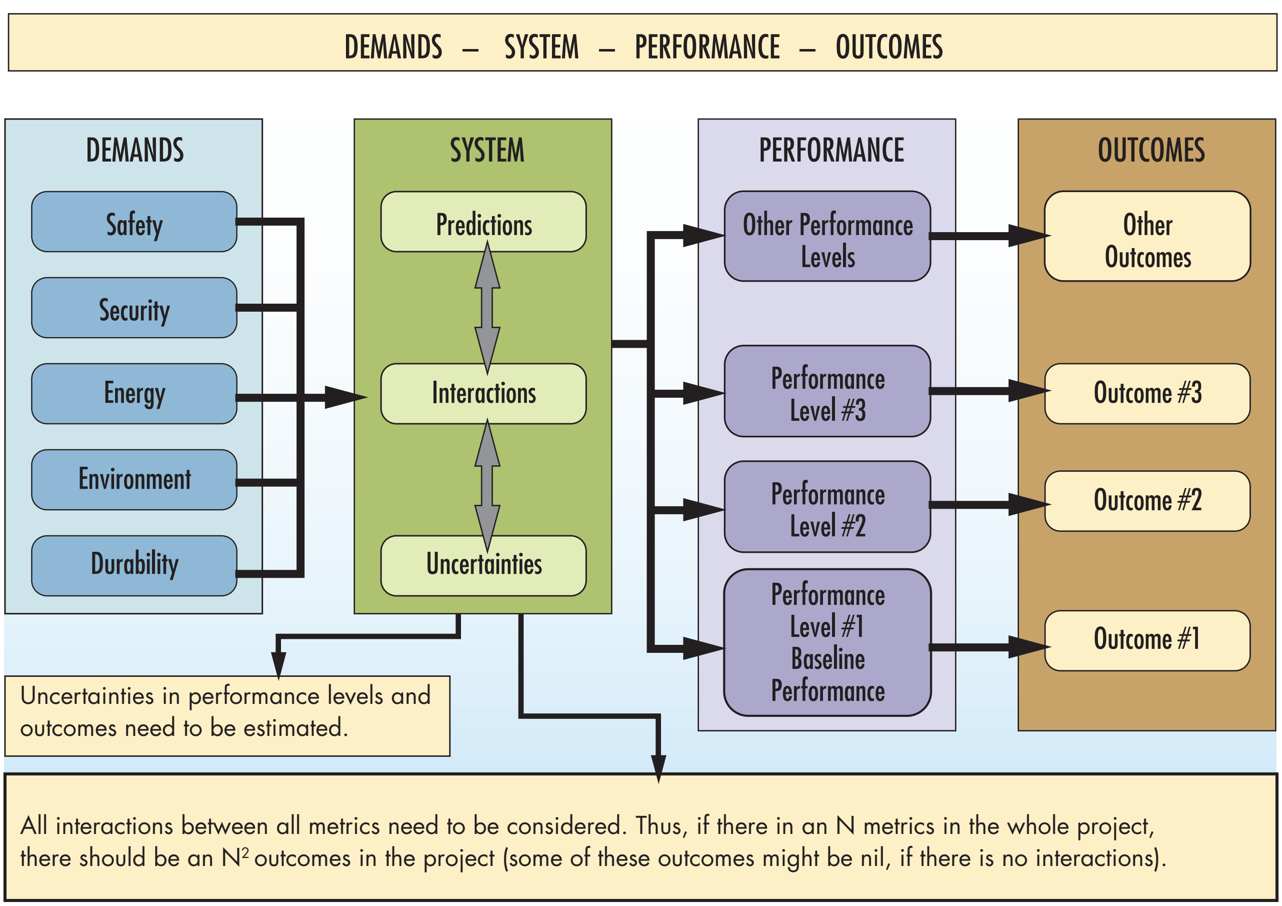

Figure 6-2: Components of Risk in the OPR Tool

The hazards (threat), $\boldsymbol{T}$ is evaluated using the demand levels targeted by the user. The vulnerabilities $\boldsymbol{V}$ are evaluated from the system predictions as estimated in the tool. Finally the consequences $\boldsymbol{C}$ are estimated using the cost outcomes calculated by the tool based on the cost predictions made by the technical experts for baseline performance upgrade costs. Figure 6-2 shows the interrelations between demands, system and outcomes in the OPR Tool. Note that the interactions within the system facilitate the evaluation of the function $\boldsymbol{f(\ )}$ numerically. Also, since the statistics of both and $\boldsymbol{V}$ and $\boldsymbol{C}$ (mean value and upper and lower limits) are computed, the mean value, upper and lower limits of risk are also evaluated by the OPR Tool.

Ettouney and Alampalli (2012) showed risk as a decision-making tool can be evaluated either on a relative or an absolute manner. The OPR Tool offers results for both relative risk and absolute risk. Relative risk is computed on a scale from 0 – 10. Absolute risk is computed using monetary values based on estimates of expenses for costs to recover from an event and return the facility to continued operation. Both relative and absolute risk can be used by the user for a rich, accurate and comprehensive decision-making process.

6.6.3 Resilience

If and/or when an asset is subjected to an abnormal event, that asset's performance/function might degrade. Such degradation of performance/function would decrease as time passes until the reasonable, or total, functionality is restored. Figure 6-3 shows time lapse of two assets that are subjected to an abnormal event that causes them to lose functionality. The curves show the functionality is restored as time passes. If we assume that resiliency is proportional to the area under the curves, it is clear that asset B is more resilient than asset A. Such an area can be used to quantify resiliency of an asset using a resiliency index.

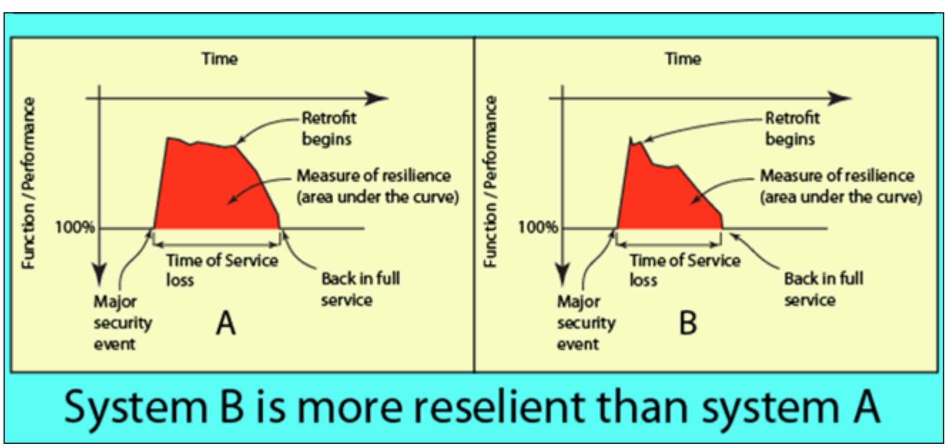

Figure 6-3: Definition of Resiliency

The Resilience metric/resiliency index, or RI in the OPR is a metric that ranges from 0 – 10. A zero RI indicates that the building under consideration does not have any resiliency at all for the hazard, or hazards, under consideration (further explanation below). An RI of 10 means that the resiliency in a building for the hazard (or hazards) under consideration is perfect.

The RI is computed using three parameters: robustness, resourcefulness, and recovery, or R1, R2, and R3 (the 3-Rs). The 3-Rs come from the National Infrastructure Advisory Council (NIAC) definition of asset (or building) resiliency. There are other definitions of resiliency that include redundancy as a 4th component of resiliency. In the OPR approach, redundancy is included within each or the 3-Rs in a variety of relatively simple ways through its relation to the other components of Risk. For example, structural redundancy is accommodated through the robustness parameter resulting from the strengthening of the building. The redundancy of water or power supplies are accommodated in the recovery parameter measure as the impact to recover from an event. And the redundancy of rescue resources is accommodated in the resourcefulness parameter scored by the model based on user inputs of project information and benchmark selections.

Each of the 3-Rs is accommodated in the OPR process through a set of relationships between robustness, resourcefulness and recovery. For example, robustness deals with issues that relate to building hardness and structural redundancies. Resourcefulness deals with training and contingency planning, and recovery deals with operational redundancies. The aggregation of the 3-Rs can then used to produce the resilience index, RI.[40] In this version of the Tool, the resiliency index is computed only using the robustness parameter, R1, which is scored based on user inputs. The parameters R2 and R3 are not included in the computations in this version due to the fact that only the building enclosure is developed in this phase. The inclusion of R2 and R3 are planned for future phases when more building systems are modeled.

Computing RI in the OPR accommodates the type of hazard or hazards of interest. There are six general hazard categories within the OPR model (blast, ballistic, CBR, seismic, wind, flood and fire). RI is computed for each of these hazards alone, or any combination of these hazards depending on the performance targets and threat levels specified. It is important to note that the inherent uncertainties in computing resiliency metrics are accommodated in the OPR algorithms. Such uncertainties

40 The current version of OPR produces only robustness estimate. The estimates of resourcefulness and recovery are going to be added in later versions.

as well as the utilization of resiliency as a decision-making tool were studied earlier by Alampalli and Ettouney (2010).

6.7 Input Processing in the OPR Tool

The processing of the Inputs provided by the user is done by the OPR Tool according to the following steps:

1. **Parametric Building Properties** – The building configuration quantities are calculated through algorithms based on the general project information provided by the user. There is a lookup table that sets the average building width based on the average floor area. In this version of the tool the only override to this is the percentage of fenestration (and therefore opaque surface area). Future versions may allow users to over-write most parametric derived outputs.
2. **Baseline Costs** – Three types of costs (provided by the project's technical experts) are employed by the OPR Tool in calculating a scenario's relative performance.
   - **Capital Expense for Functional System Groups:** CapEx1 = Qn x (CEp x CI), where Qn = quantity for each specific system group; CEp = lookup unit cost (which varies by quality level); and CI = Cost Index group, based on the city and state Location.
   - **Operating Expense** – only service and maintenance and energy are included in this category. Service and maintenance is a broad placeholder that can be over-written as $/SF. See below for energy consumption. The annual energy cost AEC = ENc1 x UEc; where ENc1 is the energy consumption, and UEc is the Unit Energy cost (see Lifecycle Information above).
   - **Recapitalization Cost** – For each functional system group, RcapEx1 = CapEx x RCF x Nrev; where CapEx1 = Capital Expense (see above), RCF = Replacement Cost Factor (including demolition or removal). RCF is a lookup value that is estimated as a percentage to return to full functionality from a demand and performance level. Nrev1 = Number of times the system is replaced in the facility life based on system and facility life values provided by the technical experts based on quality level selected.
3. **Baseline Energy** – The energy consumption (for the whole building and that portion estimated as enclosure attributable) in this phase, is a simple lookup of data provided by the technical experts as part of the architectural, fenestration and mechanical analysis based on climate zone. A more complex algorithm will be developed when the energy analysis is integral to the whole building performance.

4. **Benchmark Costs** – for upgrades from baseline to increasing levels of performance costs are calculated in the OPR model in the following ways.

   - **Capital Expense** – Expenses are evaluated first independently and then their interaction benefit or detriment is considered to arrive at total capital expense for a given level and combination of performances.

     - **Independent Values** – An extensive lookup up table is populated with benchmark factors associated with each of the building system groups, and for each of the 14 sub-attributes within those groups. There is a factor for each demand and performance combination. The Capital Expense benchmark change is: CapEx2' = CapEx1 x BnF, where BnF is the benchmark factor for each benchmark.

   - **Interaction Values** – An elaborate qualitative/quantitative assessment is computed that evaluates all sub-attribute performance as an integrated whole rather than a simple sum of the parts. The first step involves an extensive look up table completed by the technical experts and discussed above in the Interactions section of this section of the Report that identifies the qualitative impact the sub-attributes have on each other and on the facility performance (See Interactions above). The rules applied for computing the net interaction impact is as follows:

     1. If all interactions are all negative (interaction benefit), the net interaction is the greatest interaction value.
     2. If all interactions are all positive (interaction detriment), the net interaction is the highest interaction value.
     3. If there are both negative and positive interactions, then the average of all applicable interactions is used.
     4. Net CapEx2" = CapEx2' x (1+ IA), where IA is the net interaction percent.
     5. The Total Benchmark CapEx2 = CapEx1 + CapEx2"

   - Operating Expense – Operating expense is estimated for every operational sub-attribute as a percentage of the capital cost for the range of values that can deliver the target performance. Calculations are made for each sub-attribute, demand and system combination and then Interaction impacts are evaluated according to the following formulas.

  - Independent Values OpEx2 = OpEx1 + CapEx2” x OpEx’; where OpEx’ is taken from the lookup table for every demand + performance combination.
  - Interaction value is established by the same method as above.

- **Recapitalization Expense –** Recapitalization expense is computed the same way as the baseline recapitalization expense, but using benchmark frequency and cost values.
- **Recovery (Consequence) Values** ReCEx2 = CapEx2” x ReCF’; where ReCF’ is taken from the lookup table for every demand + performance combination based on estimates provided by the technical experts of requirements to return to operation from the impact of a given demand at a given level of performance.

5. **Qualitative Facility Resilience Metrics –** These judgment based weightings of degree of resilience relate to the safety and security sub-attributes only. Values used in the calculations are based on inputs made by the user for project information and benchmark selections scored based on relationships contained in the model. Weightings were developed in a related DHS project – Integrated Rapid Visual Screening of Buildings (Reference 6.12) and have been validated using numerous field visits during the development of that project. All are normalized to a scale from 1 to 10.

- **Relative Risk:** RRi = T x V x C4; where T = Threat (demand equivalent), V = Vulnerability (measure derived from user Inputs of how the building system responds to hazards), and C4 = Consequence (resultant consequence prediction at the benchmark level selected compared to maximum)
- **Resilience:** Res = Rb x (Rsr + Rcv); where Rb = Robustness (which is demand + performance); Rsr = Resourcefulness (A function of preparedness and resilience derived from relationships between user inputs), and Rcv = Recovery (value of the capital recovery cost in comparison to the maximum capital recovery cost at the highest threat and lowest benchmark level)
- **Continuity of Operations:** CoO = Rsr (Resourcefulness – function of Preparedness and Resilience. This is a qualitative measure derived from the user’s resilience benchmark selection. A fuller treatment of this metric is anticipated in subsequent phases that cover more building systems.

The formulas that perform these calculations and the data and relationships are contained in the database that underlies the OPR Tool website. The results of calculations are displayed in the OPR Tool Dashboards and Performance Requirements Report as described in Chapter 4.

6.8 Conclusions and Recommendations

As a result of the OPR Model and tool development process, the following recommendations are made to be considered in the further tool development:

1. Refinement of the OPR modeling process to simplify the identification and quantification of the Interactions between building systems and sub-attributes.
2. Streamlining of the OPR development process to increase cross-disciplinary interaction and bolster the planning phase knowledge of conceptual design and costing to increase efficiency.

6.9 References

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Validation and Verification of Results

Validation and verification of the results produced is needed for 1) the OPR Model logic and algorithms employed to interrelate components of the model for analysis and 2) the OPR Tool output. Methods evaluated for the project and how they are utilized, now or anticipated to be utilized in the future, are:

1. **Logic Employed –** Written proof through documentation of the logic employed in the expert prediction process. This applies well for many of the sub-attributes, as the OPR Tool has a significant contribution of qualitative vs. quantitative metrics. Evidence for this approach is contained in Chapters 5 and 6 of the Report.
2. **Industry Review Assessments –** Peer review of the results generated by the OPR Tool and the logic employed to produce those results. Industry review is instrumental to the credibility of the tool and the science behind it. Reviews of the Preliminary Draft Report by members of the Project Team of the logic employed and a pre-release version of the OPR Tool are being conducted as a major form of validation at this phase. Initial review by members of key industry organizations was held at a public Workshop. Further review by Industry will be sought upon release of the Report and Version

> Validation and verification of the results produced is needed for 1) the OPR Model logic and algorithms employed to interrelate components of the model for analysis and 2) the OPR Tool output.

1.0 of the OPR Tool. Commentary received will be incorporated into subsequent phases of the project.

3. **Performance Testing –** The OPR Tool will be tested and de-bugged prior to release. Tests will be conducted to ensure that the calculation algorithms are being applied correctly and that results generated are consistent with expectations.

4. **Actual Project Results –** Samples of real projects where costs are known are compared to the results generated by creating a scenario with the same characteristics as the actual project. This method will provide the most viable and customary baseline data when whole building models can be validated. It could also be used for Baseline predictions of CapEx for certain systems (basement wall, exterior opaque wall, fenestration, roof systems, and HVAC) if samples of real projects of the appropriate type and quality level could be mined for the actual costs and comparisons made to the model generated results. It is anticipated that this method will be utilized more extensively in the whole building phase.

5. **Cost Benefit and Case Study Comparisons –** In the areas of energy conservation (thermal transfer, air leakage, daylighting, natural ventilation and solar PV), and durability (water/vapor infiltration and service life), it is anticipated that case studies where both the Investment and the savings were evaluated in order to return pay back or ROI exist. These studies could have been commissioned by energy/high-performance advocacy groups or agencies, or by manufacturers of energy/performance products and systems. Results of these studies could be compared to the output generated by the tool for similar building configuration and the differences evaluated. This approach may be employed over time if appropriate studies are identified.

6. **Energy Modeling –** Using Energy Plus (or potentially other systems like Green Building Studio, eQuest and EIS) different energy related sub-attributes can be modeled individually and in combination at different demand (climate zone) and benchmark levels to provide energy consumption comparisons. Tests to isolate contribution of the enclosure to energy use when energy related factors are held constant and varied individually are being run to support the predictions for energy savings at increasing levels of performance. This approach and the results generated are addressed in the Fenestration section of Chapter 5.

7. **Means-Modeling/Testing (MMT) –** Where sufficient sampling of validation/calibration data can't be derived from the above three approaches, MMT can be used to validate and calibrate the Expert Predictions in the OPR Tool. The three approaches identified above could be used

for independent demands, especially for the safety sub-attributes. For the independent security sub-attributes involving multiple combinations of demands and performance benchmarks, the MMT may be the only validation/calibration method that is viable. The MMT process is envisioned as follows:

- **Create Baseline Models –** For this phase, a selection of exterior wall systems might be made. For the next phase where this approach is deemed to be more viable, a Whole Building Model and its Basis-of-Design (BOD) will be needed. For office buildings we anticipate starting with a small (external load driven) and a large floor plate. From these models, CapEx and OpEx and other baseline data will be estimated.
- **Upgrade the Baseline Models and BODs per selected (sample) benchmark models –** Then the estimating process would then be repeated to compute the CapEx, OpEx and consequences. The more samples, the better and potentially lower the variation.
- Process the sample Benchmark selections through the OPR Tool.
- Compare the results and resolve the differences through computing methods (approach yet to be determined). Revise and calibrate the OPR predictions accordingly.

Methods 1, 2, 3 and 5 are being employed currently. In future versions when the model is expanded to the whole building, it will be more viable to obtain the data, perform comparisons, and use the results to continuously recalibrate the predictions in the model. This is seen as an important component of the ongoing development and refinement of the OPR Model and Tool.

8

Conclusions and Recommendations

This project advances two important concepts:

1. Analyzing multiple demands and performance requirements for commercial buildings that interrelate Safety and Security along with Operational performance both independently and interactively at the same time.
2. Conducting this analysis at an early planning stage, without having to expend extensive design effort and related costs.

While using the applied methodologies in tandem is innovative, and the results obtained from applying this analysis valuable, it is also important to acknowledge that this is an early and partial implementation. Wisdom (and budget) dictated that this project not tackle the whole building, or other aspects of the building process beyond those included in this first phase so that the process could be developed in this phase and refined in subsequent phases. This is not to say that what has been accomplished is not valuable. As stated in the Introduction, given the significant role of and challenges faced by enclosure systems, providing guidance to the building owner in planning a set of Owner Performance Requirements that will optimize the building enclosure for safety, security, energy and sustainability performance is valuable and needed in its own right.

> This project advances two important concepts:
>
> Analyzing multiple demands and performance requirements for commercial buildings, and conducting this analysis at an early planning stage, without having to expend extensive design effort and related costs.

Use and evaluation by Industry will help determine the OPR Tool and Project Report's effectiveness beyond the Project Team's development efforts and internal testing performed to date. DHS and the Institute welcome that evaluation and any resulting comments. A process for contributing comments will be available on the OPR Tool website. As stated earlier comments will be incorporated into the ongoing maintenance and development planned as part of subsequent versions.

Following each of the Technical Analysis sections as well as the OPR Model chapter, Project Team members made recommendations for subsequent development efforts relevant to those sections, based on their experiences on the project. In addition to those recommendations, as it moves forward, the OPR program should:

1. Create a master plan for the DHS OPR Program that identifies objectives for expanding the scope of coverage of building systems and building types and integration with other modeling tools to obtain demand and performance input values.
2. Continue to focus on safety and security performance while cooperating and/or partnering with other agencies and stakeholders with interests in energy, environment, functionality and operability performance to broaden the base of technical expertise and decision support needs covered.
3. Develop a validation and calibration program (as identified in Chapter 7) to test the OPR Tool output that includes collaborating with other federal agencies and organizations to obtain real project data/information exchange to refine and improve the accuracy of the outcomes..

A

Attribute Performance Summary Tables

In this chapter:

The metrics and resulting performance outcomes documented in Chapter 5 for each sub-attribute are summarized in Appendix A.

Table A.1: HPBDE Attribute-Metric-Performance Summary – Facility Operations

					Metric(s)		Outcome(s)			
Attribute	Sub Attribute	Demand/Degree of Opportunity Category	Performance Benchmark	Symbol	Qualitative	Quantitative	Qualitative	Quantitative	Performance Standard	Notes
Energy Conservation	Net Energy Improvement (aggregated in tool)		Baseline Improved Performance Enhanced Performance High Performance	PB P+ P++ HP	Extent of improvement in energy usage	Net Energy Consumption Change (Kbtu/SF/Year)	NA * * *	Net Energy Consumption Change (Kbtu/ft^2/Year) Value Range	See Standards for components of Net Energy that follow	Calculated by tool from values provided
	Thermal Transfer	Climate zones CZ 1 - 8 grouped into 4 categories based on temperature and humidity	Baseline	PB	Extent of Transfer	Whole building energy consumption attributable to the Enclosure (Kbtu/SF/Year) and U Value for System type	Meets ASHRAE 90.1-2004 requirements	Whole building: Kbtu/ft^2/Year Enclosure: Kbtu/ft^2/Year Roof U value range = 0.063-0.048 Wall U value range = 0.124 - 0.057 Fenestration U value range = 0.7 - 0.35	ASHRAE 90.1 - 2004	Derived from estimates of whole building values - pending whole building analysis in Phase II.
			Improved Performance	P+			Meets ASHRAE 90.1-2010 requirements	Whole building: Kbtu/ft^2/Year Enclosure: Kbtu/ft^2/Year Roof U Value = 0.048 Wall U value range = 0.084 - 0.045 Fenestration U value range = 0.6 - 0.2	ASHRAE 90.1 - 2010	
			Enhanced Performance	P++			Meets 50% better than ASHRAE 90.1 2004 requirements	Whole building: Kbtu/ft^2/Year Enclosure: Kbtu/ft^2/Year Roof U value range = 0.039 -0.028 Wall U value range= 0.064 - 0.037 Fenestration U value range = 0.35 - 0.1	Enclosure: ASHRAE 189.1 - 2010 Whole building: ASHRAE 90.1 2004 AEDG -50%	
			High Performance	HP			Meets NZEB quality of construction	Whole building: Kbtu/ft^2/Year Enclosure: Kbtu/ft^2/Year Roof U Value = 0.017 Wall U value = 0.023 Fenestration U value range = 0.35 - 0.1	Enclosure: Passive House Whole building: ZNEB as defined by EISA 2007 or ASHRAE 90.1 2004 AEDG - 60%	
	Air Tightness		Baseline	PB	Extent of leakage/tightness	Cubic Feet/ Minute/Square Foot of Enclosure Area at 1.57 psf (75 Pa)	No control	Opaque walls: <0.03 cfm/ft^2 @ 75 Pa Fenestration: <0.3 cfm/ft^2 @ 300 Pa Whole building: <0.8 cfm/ft^2 @75 Pa	Enclosure: ASTM E 273, ASTM E 783, ASTM E1186 Whole building: ASTM E 779, ASTM C1060, ASTM E1186	In OPR Tool grouped into Net Energy Improvement based on aggregating contribution to whole building energy reduction and Carbon offset. Values to be provided from tool.
			Standard	P+			Whole building meets GSA, IBC 2012 and ASHRAE 189.1 2010 requirements	Opaque walls: <0.03 cfm/ft^2 @ 75 Pa Fenestration: <0.06 cfm/ft^2 @ 300 Pa Whole building: <0.4 cfm/ft^2 @75 Pa		
			Tight+	P++			Whole building meets NAVFAC and USACE requirements	Opaque walls: <0.015 cfm/ft^2 @ 75 Pa Fenestration: <0.03 cfm/ft^2 @ 300 Pa Whole building: <0.25 cfm/ft^2 @ 75 Pa		
			Tight+++	HP			Tight per ASHRAE Handbook of Fundamentals	Opaque walls: <0.1 cfm/ft^2 @75 Pa Fenestration: <0.02 cfm/ft^2 @ 300 Pa Whole building: <0.10 cfm/ft^2 @ 75 Pa		

Table A.1: HPBDE Attribute-Metric-Performance Summary – Facility Operations (cont.)

Attribute	Sub Attribute	Demand/Degree of Opportunity Category	Performance Benchmark	Symbol	Metric(s) Qualitative	Metric(s) Quantitative	Outcome(s) Qualitative	Outcome(s) Quantitative	Performance Standard	Notes
Sustainability	Daylighting	Category (High, Medium or Not Applicable) determines Degree of Opportunity based on climate zone.	Baseline	PB	Extant of daylighting	Reduction in Total building energy use kBtu/SF/Year	No daylighting required	No daylighting required, and no reduction in energy consumption	ASHRAE 90.1 - 2004, no daylighting requirement	In OPR Tool grouped into Net Energy Improvement based on aggregating contribution to whole building energy reduction and Carbon offset. Values to be provided from tool.
			Improved Performance	P+			Whole building meets 90.1-2010 daylighting requirements in Lighting Section 9. Window Wall Ratio is 33%.	50% reduction in lighting annual energy use in daylighting area of building. 50% of bldg has daylighting area. 5% to 2.5% reduction in whole building Kbtu/GSF/Year from baseline of no DL in 90.1 2004.	ASHRAE 90.1 - 2010, both sidelighting and toplighting daylighting requirements	
			Enhanced Performance	P++			Improved DL controls. No increase in window-to-wall ratio from 33% or daylit areas from elongating building and increasing window head height.	60% reduction in lighting annual energy use in daylighting area of building. 50% of bldg has daylighting area. 8% to 1.5% reduction in whole building Kbtu/GSF/Year from baseline of no DL in 90.1-2004	LEED EA credit 1 points in addition to ASHRAE 90.1 - 2010, both sidelighting and toplighting daylighting requirements	
			High Performance	HP			Improved DL controls. No increase in window-to-wall ratio from 33%. Increase in total wall area and in % area daylit from elongating building to 3:1 aspect ratio and increasing window head height by 2 ft.	60% reduction in lighting annual energy use in daylighting area of building./70% of bldg has daylighting area. 12% to 1.5% reduction in whole building Kbtu/GSF/Year from baseline of no DL in 90.1-2004.	LEED EA credit 1 points in addition to ASHRAE 90.1 - 2010, both sidelighting and toplighting daylighting requirements	
	Natural Ventilation	Category (High, Medium, Low) of Degree of Opportunity based on climate zone.	Baseline	PB	Extant of natural ventilation	Reduction in Total building energy use kBtu/SF/Yea	No NV requirements.	No systematic estimates of Kbtu/GSF/Year savings by climate zone and building NV features are included in this version.	No available standard	In OPR Tool grouped into Net Energy Improvement based on aggregating contribution to whole building energy reduction and Carbon offset. Values to be provided from tool.
			Improved Performance	P+			Slight energy reductions available in moist climate zones (A) in Eastern US & Canada.			
			Enhanced Performance	P++			Significant energy reductions available from night flushing etc. in dry climate zones (B) in desert & mountain areas in Western US & Canada.			
			High Performance	HP			Major energy reductions possible from NV in marine climate zones (C) along west coast.			

Table A.1: HPBDE Attribute-Metric-Performance Summary – Facility Operations (cont.)

					Metric(s)		Outcome(s)			
Attribute	**Sub Attribute**	**Demand/Degree of Opportunity Category**	**Performance Benchmark**	**Symbol**	**Qualitative**	**Quantitative**	**Qualitative**	**Quantitative**	**Performance Standard**	**Notes**
Sustainability (cont.)	Renewable Energy–Solar	Category (High, Medium, Low) of Degree of Opportunity based on climate zone.	Baseline	PB	Extant of solar power generated	Reduction in Total building energy use kBtu/SF/Yea	Offest of electrical power for lighting and plug loads at EUI for compliance with baseline annual energy consumption target value per ASHRAE 90.1-2004, **without CBR control and with and without non-customized HVAC System.**	~17-18 kBtu/GSF/yr (24 - 35% of EUI)	ASHRAE 90.1 - 2004	In OPR Tool grouped into Net Energy Improvement based on aggregating contribution to whole building energy reduction and Carbon offset. Values to be provided from tool.
			Improved Performance	P+			Offest of electrical power for lighting and plug loads at reduced EUI of 30% below ASHRAE 90.1-2004 target value, with and without semi-customized HVAC System for CBR protection (i.e., make-up and exhaust ventilation, pressurization, and filtration control).	~ 12-13 kBtu/GSF/yr (28-31% of EUI)	ASHRAE 90.1 - 2010	
			Enhanced Performance	P++			Offest of electrical power for lighting and plug loads at reduced EUI of 50% below ASHRAE 90.1-2004 target value, **with and without customized HVAC System for CBR protection** (i.e., make-up and exhaust ventilation, pressurization, and filtration control).	~9-10 kBtu/GSF/yr (30-35% of EUI)	ASHRAE 50% AEDG - 2011	
			High Performance	HP			Minimized EUI for Blast Protection and HP+ HVAC system for CBR Protection, by modifying the systems to optimize mix of non-renewable site energy resources, and by achieving ZNE with cost-effective on-site renewable energy production.	23-28 kBtu/GSF/yr (100% of EUI)	EISA-2007 - Definition of ZNEB	
Environment	Environmental Footprint (aggregated in tool)	Annual non-renewable whole building energy consumption (EUI) based on building type and carbon produced based on geographic location from map	N/A			CO_2 annual production		Lbs CO_2/prevailing regional energy production fuel type/GSF annual production	N/A	Calculated by tool from values provided
	Acoustic Transmission	Category (Severe, Significant, Moderate, Minimal) of Exterior Sound level at site	Baseline	PB	Extent of sound level allowed	Noise Criteria (NC) Composite Outdoor to Indoor Transmission Class (OITCc)	Moderate sound level, consistent with typical HVAC design for general commercial office spaces	NC -35 or higher OITCc 27 - 35	ASTM E1332-10A	
			Standard	P+			Standard sound level objective for a typical private office, consistent with typical HVAC design of private offices	NC -30 to NC -35 OITCc 27 - 40	ASTM E1332-10A	
			Quiet	P++			Quiet Sound level objective for a conference, meeting, or training room, consistent with a low noise HVAC design	NC -25 to -30 OITCc 30 - 45	ASTM E1332-10A	
			Very Quiet	HP			Very quiet sound level objective for a video conference room or facility with audio recording, consistent with a very low noise HVAC design	NC <-25 OITCc 35 - 50	ASTM E1332-10A	

Table A.1: HPBDE Attribute-Metric-Performance Summary – Facility Operations (cont.)

					Metric(s)		Outcome(s)			
Attribute	Sub Attribute	Demand/Degree of Opportunity Category	Performance Benchmark	Symbol	Qualitative	Quantitative	Qualitative	Quantitative	Performance Standard	Notes
Durability	Moisture and Service Life	See below for each Moisture and Service Life SA.	Baseline	PB			N/A	N/A		In OPR Tool results for Water Penetration, Water Vapor Migration and Service Life are grouped into Moisture and Service Life and it is expressed in terms of its level of performance only with specifics provided by values for SA performance.
			Improved Performance	P+			*	*		
			Enhanced Performance	P++			*	*		
			High Performance	HP			*	*		
	Water Penetration	Category (High, Medium, Low) based on building importance	Baseline	PB	Baseline	PSF from Pressure Test	Walls above grade, no leakage at 20% of design wind pressure or 6.24 psf, whichever is more. Walls below grade, no leakage.	6.24 PSF	Opaque walls, doors and fenestration: ASTM E 331 static water test in the lab, ASTM E1105 in the field, AAMA 501.1 dynamic testing and AAMA 501.2 for diagnostic work	
			Standard	P+	good		Walls above grade, no leakage at 20% of design wind pressure or 12psf, whichever is more. Walls below grade, no leakage.	10 PSF		
			Tight +	P++	better		Walls above grade, no leakage at 20% of design wind pressure or 15) psf, whichever is more. Walls below grade, no leakage.	15 PSF		
			Tight +++	HP	best		Walls above grade, no leakage at 20% of design wind pressure or 20 psf, whichever is more. Walls below grade, no leakage.	20 PSF		
	Water Vapor Migration	Category (High, Medium, Low) based on Climate Zone?	Baseline	PB	pass/fail	% Relative Humidity	materials will not grow mold, rot or corrode	<80%RH Eq	ASHRAE 160	
			Standard	P+	pass/fail					
			Tight +	P++	pass/fail					
			Tight +++	HP	pass/fail					
	Building Service Life	Category (A, B, C) based on class of construction quality from BOMA.	Baseline	PB	Class of service	Years of Service Life	Low end commercial	40 - 60	Professional judgement, no citable standard	
			Improved Service	P+			medium commercial	45 - 70		
			Enhanced Service	P++			high end commercial	55 - 85		
			High Service	HP			Monumental	70 - 100		
	Exterior Wall Service Life	Category (A, B, C) based on class of construction quality from BOMA.	Baseline	PB		Years of Service Life	Low end commercial	20 - 40	Professional judgement, no citable standard	
			Improved Service	P+			medium commercial	25 - 45		
			Enhanced Service	P++			high end commercial	25 - 50		
			High Service	HP			Monumental	30 - 60		

Table A.1: HPBDE Attribute-Metric-Performance Summary – Facility Operations (cont.)

Attribute	Sub Attribute	Demand/Degree of Opportunity Category	Performance Benchmark	Symbol	Metric(s) Qualitative	Metric(s) Quantitative	Outcome(s) Qualitative	Outcome(s) Quantitative	Performance Standard	Notes
Durability (cont.)	Fenestration Service Life	Category (A, B, C) based on class of construction quality from BOMA.	Baseline	PB		Years of Service Life	Low end commercial	20	Moisture Resistance Index, Werner Lichtenburger, Glass Magazine, June 2005	
			Improved Service	P+			medium commercial	25		
			Enhanced Service	P++			high end commercial	30		
			High Service	HP			Monumental	35		
	Roof System Service Life	Category (A, B, C) based on class of construction quality from BOMA.	Baseline	PB		Years of Service Life	Low end commercial	10 - 20	Professional judgement, no citable standard	
			Improved Service	P+			medium commercial	10 - 25		
			Enhanced Service	P++			high end commercial	15 - 35		
			High Service	HP			Monumental	20 - 45		

Table A.2: HPBDE Attribute-Metric-Performance Summary – Facility Resilience

Attribute	Sub Attribute	Demand/Threat	Performance Benchmark	Symbol	Metric(s) Qualitative	Metric(s) Quantitative	Outcome(s) Qualitative	Outcome(s) Quantitative	Performance Standard
Safety	Seismic Resistance	Four categories from Seismic Design Catergory A (Low) to SDC E/F (Very High)	Calculation Baseline	ReB	Extent of Damage and Continuity of Operations from a Design Basis Earthquake (10% Probability of Exceedance in 50 Years)	Glass Hazard and Enclosure Deformation Corresponding to Seismic Building Interstory Drift	Hazardous nonstructural and structural conditions may exist. Disengagement of cladding from building structure may occur. Fracturing of glass and glass fallout may occur.	> Code allowable interstory drift	IBC-2009 ASCE 7-05 ASCE 41-06 NEHRP Recommended Provisions for Seismic Regulations FEMA E-74 ASTM E 2026
			Life Safety/Code Compliant	Re+			Major, systemic damage to cladding may occur but cladding remains anchored to building structure. The exterior wall system anchorage may deform, but catastrophic failure cannot occur. Panels do not disengage from each other. Cracking and deformation to cladding may occur. Displacement and out-of-plane movements may occur. Seals and gaskets may tear/fallout and ability to provide weather protection is globally compromised. Glass breakage and fallout may occur with non-safety glazing. Structure remains stable and has significant reserve capacity; hazardous nonstructural damage is significant but controlled. Occupancy not expected after the event until repairs are performed.	Code allowable interstory drift limits: Masonry shear wall structures: 0.007h All other structures: 0.010h to 0.020h h = story height	IBC-2009 ASCE 7-05 ASCE 41-06 NEHRP Recommended Provisions for Seismic Regulations FEMA E-74 ASTM E 2026
			Reduced Damage	Re++			Moderate damage to cladding may occur but cladding remains anchored to building structure. Seals and gaskets may tear and ability to provide weather protection is locally compromised. Glass edge damage may occur and glass may fall off setting blocks, but glass breakage is mitigated. The building remains safe to occupy; structural and nonstructural repairs are minor. There shall be no failure or gross permanent distortion of the building Enclosure system anchorage and framing. Minor cracking and deformation of cladding may occur, but is not expected.	Interstory drift limits all structures: 0.0075h to 0.01h h = story height	IBC-2009 ASCE 7-05 ASCE 41 NEHRP Recommended Provisions for Seismic Regulations FEMA E-74 ASTM E 2026
			Continued Operations	HRe			Negligible structural and nonstructural damage. Minimal damage to cladding. Seals remain intact. Gaskets maybe loosened but remain functional. No glass breakage is expected. The building Enclosure system components remain in the same condition after the event as they were prior with little or no repair or replacement.	Interstory drift limits all structures: 0.004h to 0.0075h h = story height	IBC-2009 ASCE 7-05 ASCE 41-06 NEHRP Recommended Provisions for Seismic Regulations FEMA E-74 ASTM E 2026
	Flood Resistance	Four categories (Extreme, High, Medium, Low) based on combination of Depth, Velocity, Duration and Frequency of Flooding	Calculation Baseline	ReB	Level of Damage / Continuity of Operations	Building Enclosure Response to Floodwater Depth, Velocity, and Duration.	No floodproofing mitigation is provided. Severe damage and loss of operations is expected. Threat to occupants may exist.	Performance relating to flood hazard, vulnerability, consequence is measured qualatatively in the OPR tool.	IBC-2009 ASCE 7-05 ASCE 24-05 NFPA 5000
			Life Safety/Code Compliant	Re+			Building Enclosure damage requires major repair or reconstruction from exposure to floodwaters. Threat to occupants is reduced. Water damage to the building Enclosure and the interior of the facility requires major cleanup, drying, and repairs. Damage may prevent full occupancy of the facility for several weeks to months.	NA	IBC-2009 ASCE 7-05 ASCE 24-05 NFPA 5000
			Reduced Damage	Re++			The facility and building Enclosure are affected by flooding within the design flood elevation. Damage is moderate. Cleanup, drying, and moderate building Enclosure repairs and/or replacement are required. The facility can resume service in a short length of time.	NA	IBC-2009 ASCE 7-05 ASCE 24-05 NFPA 5000
			Continued Operations	HRe			The building sustains negligible nonstructural damage; the Enclosure system is fully functional. The building is immediately operational. The site is not affected by erosion. Minor damage, debris, or staining may remain, but repairs to the building Enclosure are superficial .	NA	IBC-2009 ASCE 7-05 ASCE 24-05 NFPA 5000

Table A.2: HPBDE Attribute-Metric-Performance Summary – Facility Resilience (cont.)

					Metric(s)		Outcome(s)		
Attribute	Sub Attribute	Demand/Threat	Performance Benchmark	Symbol	Qualitative	Quantitative	Qualitative	Quantitative	Performance Standard
Safety (cont.)	Wind Resistance	Four categories (Extreme, High, Medium, Low) based on combination of Wind Speed and Exposure Category.	Calculation Baseline	ReB	Level of Damage / Continuity of Operations	Glass Hazard and Enclosure Deflection	Hazardous nonstructural damage may exist. Moderate glass breakage may occur. Permenant deformation of cladding may exist. Damage may impact operations.	Glazing hazard is moderate. Cladding deflection > serviceability limits per code. Permanent deformation of cladding at overload (150% design load) > 0.2% of clear span. Major impacts to serviceability.	IBC-2009 ASCE 7-05 ASTM E 330 ASTM E 1300 ASTM E 1996/1886
			Life Safety/Code Compliant	Re+			Hazardous nonstructural damage is controlled. Moderate damage to building Enclosure cladding and components may occur. There shall be no gross failure of building enclosure system anchorage. Minor deformation and permanent set of main framing members may occur. No falling hazards should occur.	Glazing hazard is low (8/1000 breakage probable). Deflection within code limits of L/175 for frames supporting glass, L/240 for walls with brittle finishes, L/120 for walls with flexible finishes. Permanent deformation of cladding at overload (150% design load) < 0.2% of clear span. Minor impacts to serviceability.	IBC-2009 ASCE 7-05 ASTM E 330 ASTM E 1300 ASTM E 1996/1886
			Reduced Damage	Re++			The building remains safe to occupy; nonstructural repairs are minor. There shall be no failure or gross permanent distortion of the building enclosure system anchorage and framing. Moderate disengagement of gaskets and failure of sealants may occur. Minor cracking and deformation of cladding may occur, but is not expected. No falling hazards allowed.	Glazing hazard is minimal. Deflection less than code allowable. Permanent cladding deformation at overload (150% design load) < 0.05% of clear span. Negligible impacts to serviceability.	IBC-2009 ASCE 7-05 ASTM E 330 ASTM E 1300 ASTM E 1996/1886
			Continued Operations	HRe			There is negligible structural and nonstructural damage. The building enclosure system components remain in the same condition after the event as they were prior with little or no repair or replacement.	No glazing hazard. Deflection less than code allowable. No permanent cladding deformation at overload (150% design load). No impacts to serviceability.	IBC-2009 ASCE 7-05 ASTM E 330 ASTM E 1300 ASTM E 1996/1886
	External FIre Resistance	Three categories (High, Medium, Low) based on Input from User that equates to level of Fire Risk	Calculation Baseline	ReB	Extent of Damage	Measurement of Allowable Impact	Structure remains stable and has significant reserve capacity; hazardous nonstructural damage is controlled. The exterior wall system anchorage may deform, but catastrophic failure cannot occur. Moderate disengagement of gaskets and failure of sealant is expected to occur. Moderate cracking, melting and charring to cladding may occur. No falling hazards allowed. Repair possible, but may be economically impractical. Ignition of significant fire inside.	NA	Ignition: NFPA 259 Flame propagation resistance: NFPA 285 Ignition and flame spread on roof coverings: ASTM E108 Exterior fire barrier: ASTM E2707
			Code Compliant	Re+					
			Reduced Damage	Re++			The building remains safe to occupy; structural and nonstructural repairs are minor. There shall be no failure or gross permanent distortion of exterior wall system anchorage and framing. Minor disengagement of gaskets and failure of sealants may occur. Minor cracking, melting or charring of cladding may occur, but is not expected. No falling hazards allowed. Ignition of minor item inside structure, no spread from initial item.	1 hour fire resistance rating, openings not protected.	Ignition: NFPA 259 Flame propagation resistance: NFPA 285 Ignition and flame spread on roof coverings: ASTM E108 Exterior fire barrier: ASTM E2707 Insulation: ASTM E119/NFPA 251 Collapse: ASTM E119/NFPA 251
			Continued Operations	HRe			Negligible structural and nonstructural damage. The exterior wall system components remain in the same condition after the event as they were prior with little or no repair or replacement.	2 hour fire resistance rating, openings protected.	Ignition: NFPA 259 Flame propagation resistance: NFPA 285 Ignition and flame spread on roof coverings: ASTM E108 Exterior fire barrier: ASTM E2707 Insulation: ASTM E119/NFPA 251 Collapse: ASTM E119/NFPA 251 Doors: NFPA 252 Windows: NFPA 257

Table A.2: HPBDE Attribute-Metric-Performance Summary – Facility Resilience (cont.)

					Metric(s)		Outcome(s)		
Attribute	Sub Attribute	Demand/Threat	Performance Benchmark	Symbol	Qualitative	Quantitative	Qualitative	Quantitative	Performance Standard
Security	Blast Protection	Three categories (High, Medium, Low) based on combination of Standoff distance and Charge strength	Failure	ReB	Level of Damage / Continuity of Operations	Glass Hazard & End Rotations / Ductility	Some hazard mitigated through use of anti-shatter materials. Components fail during blast and require full replacement. Building is not operational.	Glazing Hazard = High / Component End Rotations>6°	UFC 4-010-01 PDC-TR 06-08 ISC Physical Security Criteria for Federal Facilities
			Major Damage	Re+			Large deformations of enclosure components expected. Some regions of high hazard may occur. Affected components not economically repairable and require replacement. Facility is not operational.	Glazing Hazard = Low / Component End Rotations<4°	UFC 4-010-01 PDC-TR 06-08 ISC Physical Security Criteria for Federal Facilities
			Medium Damage	Re++			Enclosure components deform beyond elastic limit but limit debris that enters building. Some components require replacement. Portions of the building are not operational.	Glazing Hazard = Minimal / Component End Rotations<2°	UFC 4-010-01 PDC-TR 06-08 ISC Physical Security Criteria for Federal Facilities
			Minor Damage	HRe			Occupants Protected. No permanent deformations to enclosure components. Continued operations. Some minor repairs to maintain weather tightness of building are expected.	Glazing Hazard = None / Component Ductility<1	UFC 4-010-01 PDC-TR 06-08 ISC Physical Security Criteria for Federal Facilities
	Ballistic Protection	Three categories (High, Medium, Low) corresponding to UL 752 defined levels I, III, VI for impact strength	No Protection	ReB	Weapon Capable of Resisting	No. of shots, weight, caliber and velocity of round	No ballistic protection	N/A	None
			Life Safety	Re+			Components provide protection from Level I (9mm FMCJ w/ lead core) ballistic demand. Replacement of affected elements required post-event.	3 shots-8.0g-9mm-394m/s	UL 752
			Reduced Damage	Re++			Components provide protection from Level III (.44 Magnum lead SWC, gas checked) ballistic demand. Replacement of affected elements required post-event.	3 shots-15.6g-11.18mm-453m/s	UL 752
			Continued Operations	HRe			Components provide protection from Level VII (5.56 rifle, FMCJ with lead core) ballistic demand. Replacement of affected elements required post-event.	5 shots-3.56g-5.66mm-1033m/s	UL 752
	External CBR Protection	Three categories of Exposure (High, Medium, Low) based on combination of Contaminant type, Concentration, Release Location and Duration	No Protection	ReB	Extent of Vulnerability	Measurement of allowable impact	Major disruption or failure in system performance or significant impact on health/safety may occur.	Enclosure integrity and make-up air particulate filters (i.e., MERV 8 - 13) are to be in compliance with ASHRAE Standard 90.1-2004. No chemical filtration of make-up air and no active pressurization control for the perimeter zones or enclosure is provided.	ISC-2009 (ref 12), ASHRAE 29-2009 (ref 13), NRC-2007 (ref 14), ASHRAE 90.1-2004 (ref 19) ASHRAE 52.2-2007(ref 32), AMCA-500-D-07 (ref 35).
			High Vulnerability	Re+			Significant Disruption in System Performance or some Impact on Health/ Safety is expected when fenestrations are closed;	Enclosure integrity and make-up air particulate air filters (i.e., MERV 9 - 13) are to be in compliance with ASHRAE Standard 90.1-2010. Also to be provided is chemical filtration of make-up air with low to medium efficiency (e.g., 30 - 60%) and appropriate impregnated activated carbon, and active pressurization control (Δ10% difference between make-up and exhaust airflow rates) for the perimeter zones.	ISC-2009 (ref 12), ASHRAE 29-2009 (ref 13), NRC-2007 (ref 14), ASHRAE 90.1-2010 (ref 20) ASHRAE 52.2-2007(ref 32), ASHRAE 145.2-2010 (ref 33), AMCA-500-D-07 (ref 35).

Table A.2: HPBDE Attribute-Metric-Performance Summary – Facility Resilience (cont.)

					Metric(s)		Outcome(s)		
Attribute	Sub Attribute	Demand/Threat	Performance Benchmark	Symbol	Qualitative	Quantitative	Qualitative	Quantitative	Performance Standard
Security (cont.)	External CBR Protection (cont)	Three categories of Exposure (High, Medium, Low) based on combination of Contaminant type, Concentration, Release Location and Duration	Moderate Vulnerability	Re++	Extent of Vulnerability	Measurement of allowable impact	Some disruption is expected in system performance; no impact is expected on health/safety, but some discomfort is likely when fenestrations are closed.	Enclosure integrity is to be in compliance with ASHRAE Standard 189.1-2009 or ASHRAE 50% AEDG, make-up air particulate air filters are to be MERV 13 - 17 and chemical filters are to be medium to high efficiency (e.g., 60 - 95%) with appropriate impregnated activated carbon, and active pressurization control (e.g., > 0. 05 in w.g. difference between inside to outside air pressures) is to be provided across all enclosure surfaces	ISC-2009 (ref 12), ASHRAE 29-2009 (ref 13), NRC-2007 (ref 14), ASHRAE 90.1-2010 (ref 20) ASHRAE 52.2-2007(ref 32), ASHRAE 145.2-2010 (ref 33), AMCA-500-D-07 (ref 35).
			Low Vulnerability	HRe			Negligible disruption in system performance and no impact on health/safety is expected when fenestrations are closed.	Enclosure integrity is to be in compliance with ASHRAE Standard 189.1-2009 or ASHRAE 50% AEDG, make-up air particulate air filters are to be MERV > 17 (e.g., HEPA) and chemical filters are to be high efficiency (e.g., > 95%) with appropriate impregnated activated carbon, active pressurization control (> 0. 05 in w.g. difference between inside to outside air pressures) is to be provided across all enclosure surfaces when fenestrations are closed, CBR detection technology is to be installed to protect critical areas against known credible threats, and control strategies are to be installed for system shut-downs without exacerbating occupant exposure to externally released CBR agents.	ISC-2009 (ref 12), ASHRAE 29-2009 (ref 13), NRC-2007 (ref 14), ASHRAE 90.1-2010 (ref 20) ASHRAE 52.2-2007(ref 32), ASHRAE 145.2-2010 (ref 33), AMCA-500-D-07 (ref 35).

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B

EnergyPlus Simulation Analysis

In this chapter:

The EnergyPlus simulation summarized in Chapter 5 is documented in detail in Appendix B.

Appendix B: EnergyPlus Simulation Analysis Table of Contents

Figures

Tables

Appendix to the Fenestration Technical Analysis: Preliminary EnergyPlus Simulation Results for a Medium Office Building

J. Elliot Nahman & Joseph J. Deringer, Institute for the Sustainable Performance of Buildings (Superb)

Superb, using PNNL's 90.1–2004 and –2010 Energy Plus[1]reference models[2], ran a series of energy simulations examining the impact on energy performance of various improvements in the building enclosure.

B-1 Methodology

B-1.1 Climate Zones and City Locations

Simulations were run for all US (and one Canadian) climate zones and accounted for climate type. Table B-1 shows which cities fall into each climate type-zone pair.

Table B-1 List of Climate types, zones, and the city associated with each

C: Marine	B: Dry	A: Moist
3C: San Francisco, CA	2B: Phoenix, AZ	1A: Miami, FL
4C: Salem, OR	3B: El Paso, TX	2A: Houston, TX
5C: Vancouver, BC	4B: Albuquerque, NM	3A: Memphis, TN
	5B: Boise, ID	4A: Baltimore, MD
	6B: Helena, MT	5A: Chicago, IL
		6: Burlington, VT
		7: Duluth, MN

Summary results are presented in this Appendix for 7 of these 15 cities, which are:

C: Marine	B: Dry	A: Moist
	2B: Phoenix, AZ	1A: Miami, FL
	4B: Albuquerque, NM	2A: Houston, TX
	6B: Helena, MT	4A: Baltimore, MD
		6: Burlington, VT

1 Energy Plus and Energy Plus Open Studio for Google Sketchup plugin http://apps1.eere.energy.gov/buildings/energyplus/

2 Pacific Northwest National Laboratory (PNNL) 90.1 Prototype Building Models http://www.eia.gov/cneaf/electricity/epm/epm_sum.html

The PNNL simulations used older TMY2 weather files for doing simulations for the 15 city locations. Superb switched to the newer TMY3 weather files, which provide more accurate results.

TMY2 files tend to under-estimate the amount of solar radiation hitting window surfaces. As one can see in the graph below, in general this has the effect of reducing the cooling load in the southern climate zones, and increasing the heating load in the northern zones.

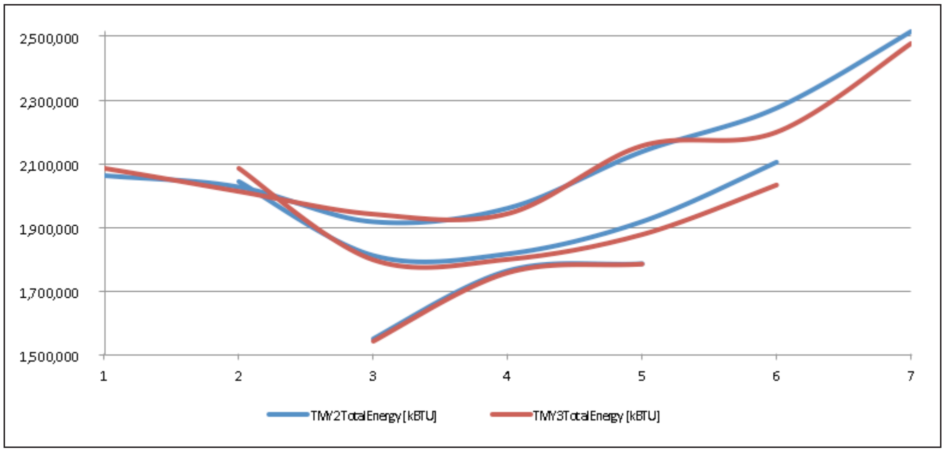
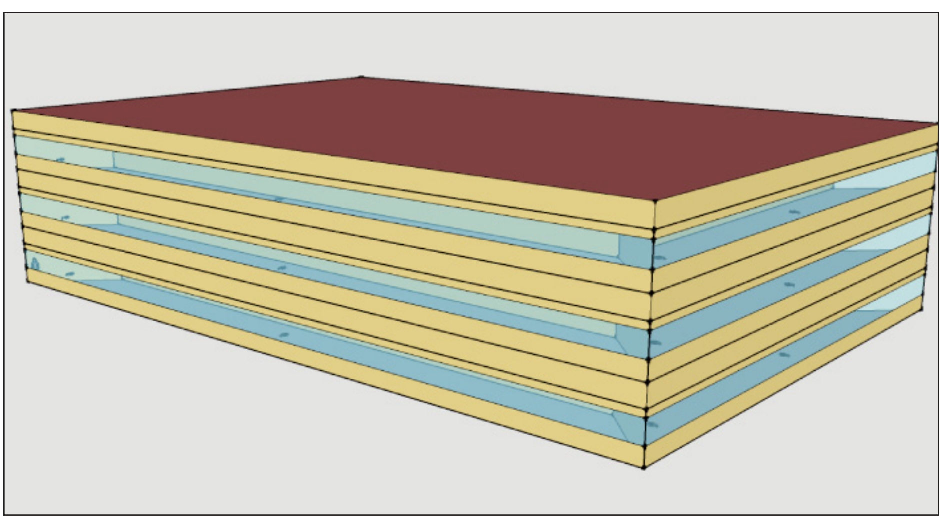


Figure B-1:
Comparison of Simulation results using TMY2 vs TMY3 weather files

In Figure B-1 the vertical axis is kBtu of whole building energy use while the horizontal axis is for climate zones (CZ) 1 to 7.

B-1.2 Medium Office Building

These simulations results contained in this report were for a three-story medium office building, 53,628 gross square feet (GSF) in size. Each floor is modeled as five thermal zones, four perimeter and one core.



B-1.3 Original Files

The PNNL information for the medium office contained a separate EnergyPlus input file for each of the 15 cities and for each of the two vintages of ASHRAE standard, 90.1-2004 and 90.1-2010[3], for a total of 30 versions of the medium office building, each with slight variations in HVAC system inputs and other inputs.

B-1.4 Creation of a Single Parametric File

Superb analyzed the difference among the files and created a single parametric input file to use in generating consistent and systematic simulations for various building features:

- Climate locations
- Levels of energy standard
- Window-to-wall ratios
- Building aspect ratios, and
- Building enclosure performance for a the following enclosure attributes:
  - Roof insulation
  - Wall insulation
  - Infiltration levels
  - Fenestration U-value, SHGC, and Visible Light Transmission (VLT)
  - Shading of fenestration with both fixed and dynamic shading devices
  - Advanced daylighting options

The parametric input files were based off of PNNL's 2004 and 2010 reference building simulation models for a medium office building. These models were separated into "include" files that are called from the main input file, for each set of building systems so as to make it easier to standardize, modify, and include the necessary files for each run. Building enclosure systems were isolated and a combination of outside scripts and

3 ANSI/ASHRAE/IESNA Standard 90.1-2004 Energy Standard for Buildings Except Low Rise Residential Buildings,

ANSI/ASHRAE/IESNA Standard 90.1-2010 Energy Standard for Buildings Except Low Rise Residential Buildings.

Energy Plus macro language was used to adjust the variables based on performance level and climate zone.

Other systems, such as the HVAC and lighting systems and the internal loads, were taken from the 2010 PNNL file. These 2010 vintage systems were compliant with the prescriptive requirements of ASHRAE 90.1-2010. We applied these 2010 vintage HVAC and lighting systems and internal loads to all four performance levels we have been simulating in order to isolate the energy performance of the enclosure measures of interest, the four levels are:

1. (BP) Baseline, 90.1-2004
2. (P+) Improved, 90.1-2010
3. (P++) Enhanced, projected to have 50% better energy performance than 90.1-2004.
4. (HP)High Performance, Net Zero Energy Building (NZEB)

Using this approach allowed us to isolate the performance of the individual enclosure measures across the four levels of energy performance (BP, P+, P++, and HP).This is an important and highly useful result of these simulation studies conducted in Phase 1.

When we assess individual advanced enclosure measures it is sometimes difficult to place them clearly into specific P++ and HP levels. At the end of this appendix, in the last section, we have listed combinations of advanced measures that show energy conservation reductions from the baseline for each of three levels - P+, P++, and HP. This is another significant result of these simulation studies.

Modified Whole Building Energy Performance Levels

Also, using this approach also produces *modified* whole building energy performance levels, or Energy Use Indices (EUIs) for the 90.1-2004 Baseline that are lower than the original baseline, because 2010 vintage HVAC and lighting systems are used.

The table and figure below compares the original EUIs for 90.1- 2004 and 90.1-2010 from the PNNL files with the modified EUIs produced by our modified input files that use processed 2010 HVAC and lighting systems and 2010 internal loads. The medium office building has a baseline WWR = 0.33 (windows are 33% of total wall area).

Table B-2 Comparison of EUIs from PNNL files and modifications by SuPerB.

	2004			2010		
	PNNL TMY2	PNNL TMY 3	Superb Base	PNNL TMY2	PNNL TMY 3	Superb Base
1(A) Miami	54.3	55.0	43.6	41.4	41.9	41.2
2(A) Houston	55.0	54.4	41.8	40.7	40.4	39.4
4(A) Baltimore	55.8	55.8	43.0	39.3	39.0	39.1
6(A) Burlington	63.0	61.3	48.6	45.6	44.1	44.6
2(B) Phoenix	54.5	55.4	43.1	41.0	41.9	40.6
4(B) Albuquerque	49.7	49.2	39.1	36.4	36.1	36.0
6(B) Helena	58.0	56.3	44.1	42.2	40.8	40.8

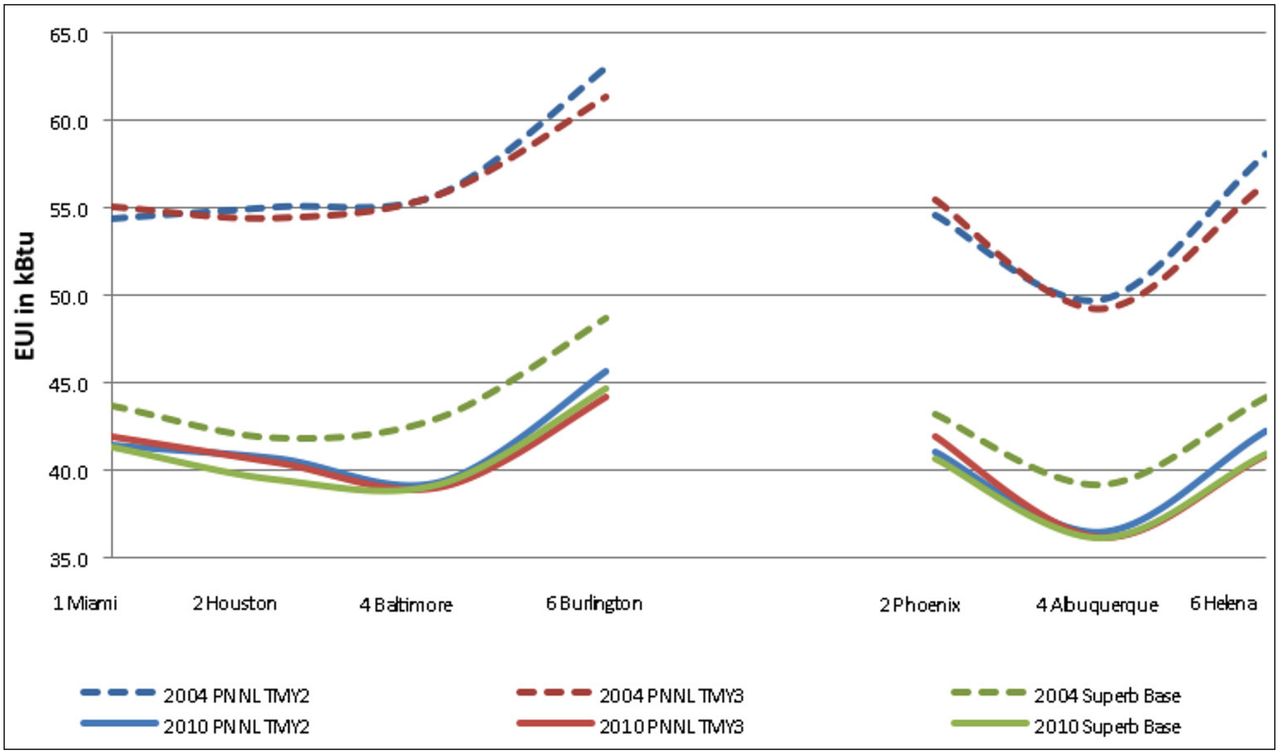


Figure B–2: EUI Comparison of PNNL base files and modifications by SuPerB

The dashed lines in the chart represent the 2004 files, the solid the 2010 files. The weather files originally packaged with the PNNL files were TMY2, but TMY3 is the accepted weather file format for Energy Plus. Runs were made on the PNNL files for both TMY2 and TMY3; the SuPerB runs used TMY3.

Because SuPerB has substituted 2010 vintage lighting and HVAC systems, in the PNNL 2004 results are markedly different from SuPerB's results:

- The PNNL 2004 baseline building file includes:
  - 2004 lighting system inputs
  - 2004 HVAC system inputs
  - 2004 enclosure system inputs
- The modified 2004 baseline file generated by SuPerB includes:
  - 2010 lighting system inputs
  - 2010 HVAC system inputs
  - 2004 enclosure system inputs

Thus, the 2004 Modified baseline has much more efficient lighting and HVAC systems than the original PNNL 2004 reference building baseline. Superb normalized the HVAC system and energy features to those used in 90.1-2010 in order to isolate the energy impacts of variations in the enclosure variables.

The 2010 results for PNNL TMY3 and for SuPerB TMY3 are all comparable; only slight differences exist.

The above chart implies that much of the improved energy performance from 90.1-2004 to 90.1-2010 is from the HVAC and lighting requirements, and that the building enclosure improvements are smaller.

B-1.5 Two Levels of 90.1 Energy Standards Examined

For the medium office building case, we simulated the single building file with changes in selected inputs that represented exact compliance with the prescriptive requirements of two vintages of ASHRAE/IES Standard 90.1:

- 90.1-2004 (with WWR= 0.33 and compliance with all 2004 prescriptive enclosure measures)
- 90.1-2010 (with WWR= 0.33 and compliance with all 2010 prescriptive enclosure measures, including continuous air barriers and daylighting).

The 2004 vintage of 90.1 does not include prescriptive requirements for either continuous air barriers or for daylighting, where as the 2010 vintage does include prescriptive requirements for continuous air barriers plus daylighting for both sidelighting from vertical fenestration and for toplighting from skylights or roof monitors.

To isolate the benefits from the 90.1-2010 prescriptive daylighting requirements as a measure we simulated the 90.1-2004 Baseline building both with and without the 90.1-2010 prescriptive daylighting input specifications used in the PNNL 90.1-2010 building files, and we simulated the 90.1-2010 inputs both with and without the new daylighting prescriptive requirements specified in 90.11-2010. Thus, we simulated four levels:

- 90.1-2004, with no prescriptive requirements for daylighting (the 2004 baseline condition)
- 90.1-2004, with the 90.1-2010 prescriptive requirements for daylighting added
- 90.1-2010, with no prescriptive requirements for daylighting included
- 90.1-2010, with prescriptive requirements for daylighting (the 2010 benchmark condition)

B-1.6 Window-to-Wall Ratio (WWR)

We have also sought to evaluate the impact on energy performance of variation in window-to-wall ratio (WWR), since the amount of glazing can have a major impact on energy performance. Baseline WWR for the PNNL Reference Office Buildings varies by building size:

- WWR = 0.20 for the small office (windows are 20% of total wall area).
- WWR = 0.33 for the medium-size office (windows are 33% of total wall area).
- WWR = 0.40 for the large office (windows are 40% of total wall area).

Also, a key WWR level for standard 90.1 is WWR =0.40 (windows at 40% of total wall area), since WWR = 0.40 is a breakpoint in the application of 90.1 compliance approaches. WWR = 0.40 is the maximum level for which the enclosure prescriptive requirements can be used. If a building design has WWR > 0.4, in either an ECB compliance analysis or in a LEED analysis its baseline variation must be set to have a WWR = 0.4 for whole building energy analysis purposes (see the ECB method in section 11 and Appendix G in 90.1-2004 and 90.1-2010). Conversely, if a building design has a WWR< 0.4 (say, WWR = 0.33), then it is simulated using its proposed WWR (0.33) and not WWR = 0.40.

To assess the impact of WWR across a reasonable range in the expected range of glazing in many office buildings, we have simulated the medium office building at several levels of WWR including:

- 0.20
- 0.33
- 0.40
- 0.60

B-1.7 Energy Performance for Selected Enclosure Attributes

We have also simulated the energy performance of three types of building enclosure attributes, both singly and in combination. These include:

General Enclosure Measures

Such measures apply to the entire building enclosure. The measures we have examined include:

- Reduced infiltration due to use of a continuous air barrier: 0.2 cfm/ft^2 and 0.1cfm/ft^2.

Opaque Enclosure Measures

Such measures apply just to the opaque portions of the building enclosure. The measures we have examined include:

- Increased wall insulation, relative to a baseline condition of prescriptive requirements in 90.1-2010.
- Increased roof insulation, relative to a baseline condition of prescriptive requirements in 90.1-2010.

Fenestration Measures

Such measures apply just to the fenestration portions of the building enclosure. The measures we have examined include:

- High performance windows, with either low U-Factor values or high Visible Transmittance values, or both, as shown in Table B-3 below.
- Fenestration assemblies supplemented by fixed external shading (overhangs).
- Fenestration assemblies supplemented by dynamically controlled external shading (louvers).
- Dynamic windows, using electro chromic technology

- Basic daylighting measures, as incorporated in the 90.1-2010 version of the original building model received from PNNL.
- Advanced daylighting, with continuous dimming, and increasing the percentage of building floor area using daylighting via a combination of (1) higher window head heads yielding deeper daylighting penetration into the building, and (2) an elongated building configuration.

The Window 6 program has been used to identify properties of fenestration assemblies for use in these simulations.[4] As much as possible we have endeavored to select fenestration assemblies that represent actual fenestration products on the market.

Table B–3: Selected High Performance Windows, from a baseline of 90.1-2004 and 90.1-2010

	Base(2004 & 2010)	Advanced Double Pane (High VT)	Advanced Triple Pane #1 (High VT, Low U)	Advanced Triple Pane #2 (High VT & SHGC, Low U)	Quad Pane	EC off (approx.)	EC on (approx.)
CZ 1,2,3							
U Value	0.56	0.36	0.18	0.14	0.10	0.30	0.30
SHGC	0.25	0.25	0.39	0.47	0.29	0.48	0.14
Tvis	0.35	0.57	0.6	0.61	0.45	0.65	0.10
CZ 4,5,6							
U Value	0.47	0.35	0.18	0.14	0.10	0.30	0.30
SHGC	0.39	0.35	0.39	0.47	0.29	0.48	0.14
Tvis	0.60	0.62	0.60	0.61	0.45	0.65	0.10

B-1.8 Energy Modeling Issues in Phase 1

Impacts of Variation in Building Size

The whole building simulation results for medium offices used in this analysis may differ somewhat from those for ”small buildings” (e.g., < 15,000 ft^2 floor plate), which may be dominated by thermal loads through the enclosure, and for “large buildings” (e.g., > 60,000 ft^2 floor plate), which may be dominated by internal loads. Enclosure parameters may have more impact on whole building energy use for small buildings than for large buildings,

4 Lawrence Berkeley National Laboratory, Window 6.3 software http://windows.lbl.gov/software/window/6/index.html

but many interrelated factors can influence the magnitude of enclosure impacts on whole building energy use (e.g., ratio of interior to perimeter zones, window to wall ratios, building form and orientation, intensity of internal loads from office equipment, etc) and one should be cautious about attempting generalizations. In particular, too many exceptions exist to allow one to simply assume that smaller offices are externally load dominated while larger buildings are internally load dominated. For example, smaller office buildings typically have less window area than larger offices. Average window-to-wall ratios (WWRs) for offices vary by office size:

- WWR = 20% for small offices
- WWR = 33% for medium offices
- WWR = 45% for large, high-rise offices

Conversely, small offices may have higher occupancy densities than large offices. Thus, small offices might have higher internal loads and lower external loads than large offices. This is the opposite of conventional assumptions. Such factors will be addressed in the OPR tool by accounting for variations in WWR and in occupancy and equipment load densities.

Glare Control

In general, the modeling rules in 90.1 Appendix G have in the past ignored glare considerations irrespective of use of daylighting, but glare-related modeling rules have recently changed in the 90.1-2010 version of Appendix G. Glare can be a serious issue for visual comfort when large window areas are used as is common in office buildings. While not all Phase 1 daylighting analyses addressed glare controls, the combined analyses described in Section 5.3 did include external shading plus daylighting for most climate locations. The external shading did provide some glare control, relative to the non-daylighting cases. This topic is discussed in more detail in Appendix A. Further examination of this issue should be analyzed in future phases of this project.

While not all Phase 1 daylighting analyses addressed glare controls, the combined analyses described in Section 5.3 did include external shading plus daylighting for most climate locations. The external shading did provide some glare control, relative to the non-daylighting cases. This topic is discussed in more detail in report is being written in an office that often has glare conditions from large glazed areas facing south and west. Even when all venetian blinds are closed to reduce glare, the electric lighting system is not on during daytime hours. The absence of glare controls in a parametric computer analysis of general conditions certainly does not lead to an conclusion of overestimation of daylight benefits.

B-2 Early Simulation Results for Standard 90.1-2004 and 90.1-2010

As we began the simulation effort, we produced some early results that are more generalized but still have value. They are presented in this section. More recent simulations results are presented in later sections of this report.

Figure B-3 Total Building Energy Use by climate type and zone in kBTU/GSF/yr, shows a summary of the results for both 90.1 runs across all fifteen climate zones and separated by climate type. Solid lines show the 90.1-2004 results for the original PNNL models and the dashed lines show the 90.1-2010 results.

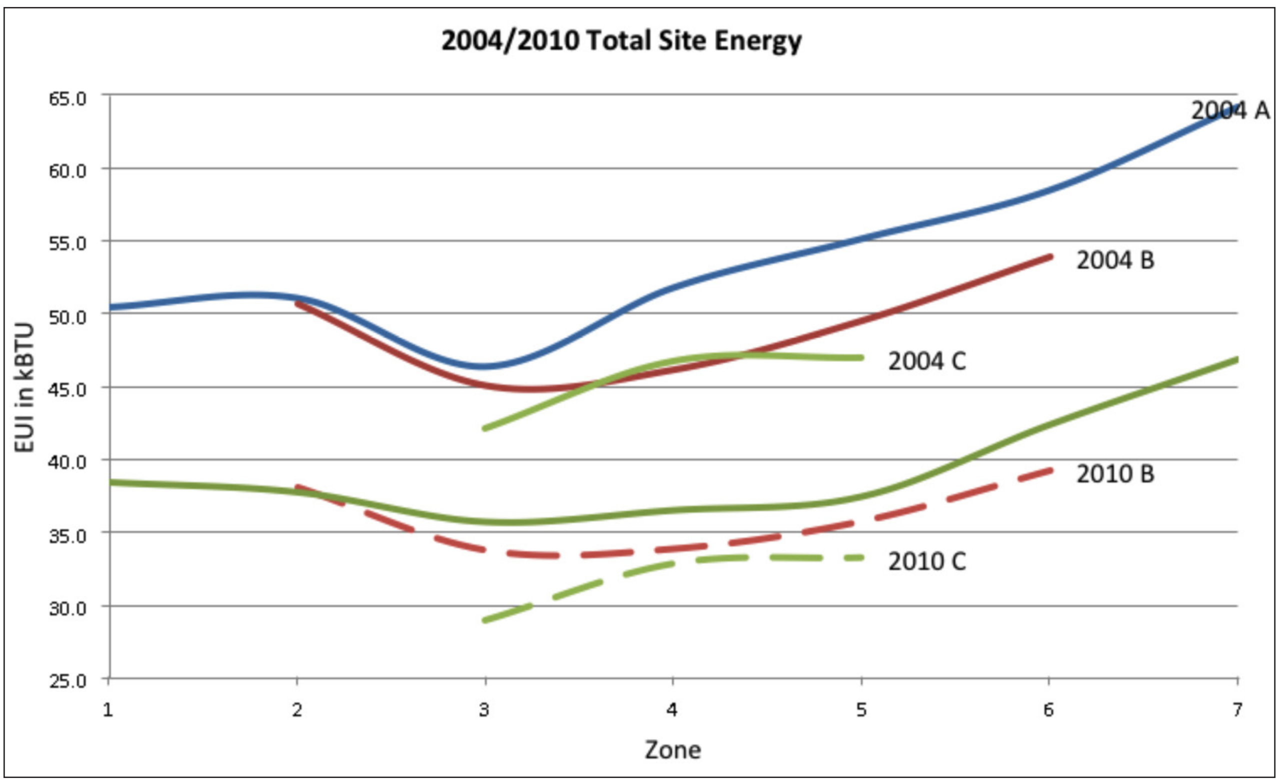


Figure B-3: Total Building Energy Use by climate type and zone in kBTU/GSF/yr,

What is interesting to note is that in all climate types — Moist, Dry, and Marine — the lowest energy use occurs in zone 3, which makes intuitive sense. Zones below 3 have greater air conditioning loads while zones above 3 have greater heating loads; the cross-over point is zone 3. Also interesting is the nearly flat line between zones 1A–2A and 4C–5C.

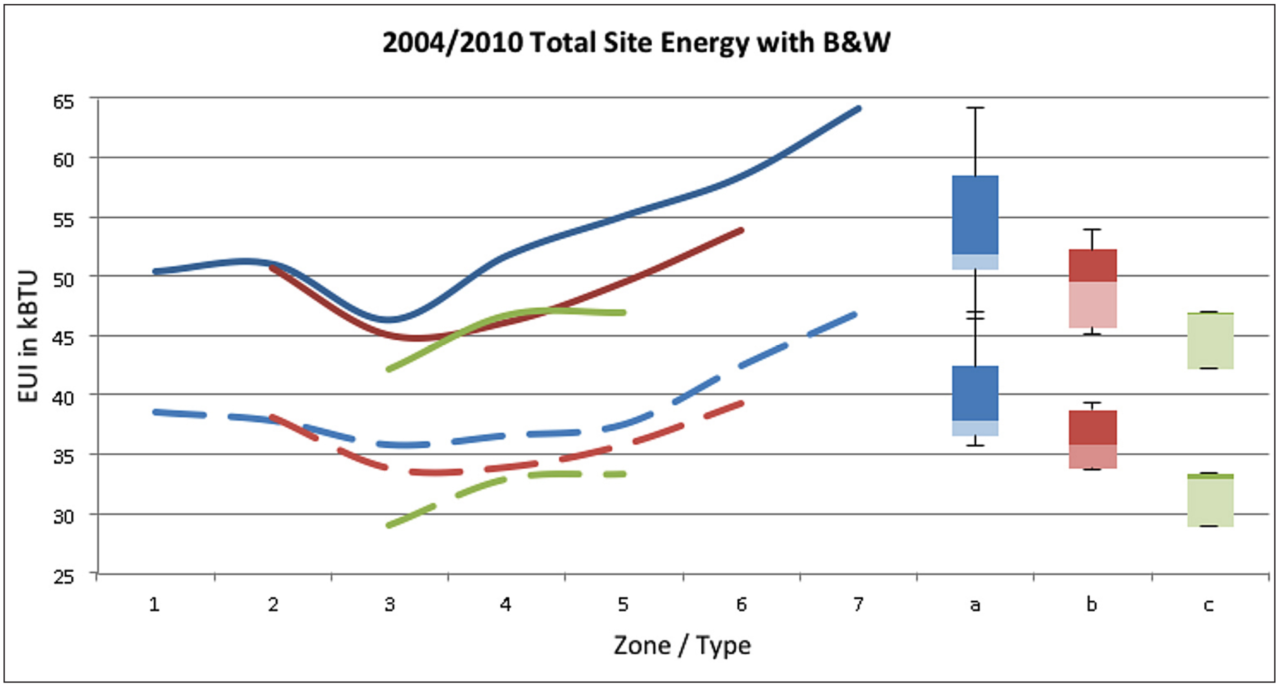


Figure B-4: Whole Building Site Energy use with Box and Whisker plots added for each climate type, in kBTU/GSF/yr,,

Adding box and whisker plots to the graph (Figure B-4) helps to clarify the difference in energy use between the two versions of 90.1. Generally, there is a drop on the order of 28% between the two standards. Table B-4 outlines the percent reduction of 90.1-2010 from -2004 using both the mean value and the median values across the climate zones. As one can see, it yields only minor differences.

Table B-4: Percent Differences between 2010 and 2004 by climate type

2010/2004 Difference	Mean	Median
A: Moist	27%	27%
B: Dry	26%	28%
C: Marine	30%	30%

Figure B-5 and Figure B-6 look at end use profiles for different zones by year. The outer pie chart is for 90.1–2004 and the inner is –2010. The area of these two charts corresponds to the total energy use simulated for both versions. As may be expected, the portion of energy used in conditioning the building shrinks from 2004 to 2010, while the plug loads grow to be a large portion of the energy pie. In effect, one can see the differing rates of energy reduction among the different systems. Although reductions in energy use occurred in all the systems except the water systems, the change in their energy use were smaller in some systems than in other systems, causing their piece of the energy pie to grow. Figure B-7 includes two graphs that are a series of bar charts showing the absolute end use energy so you can see the drops in end use energy consumption between the two standards. Water systems have no change between 90.1–2004 and –2010.

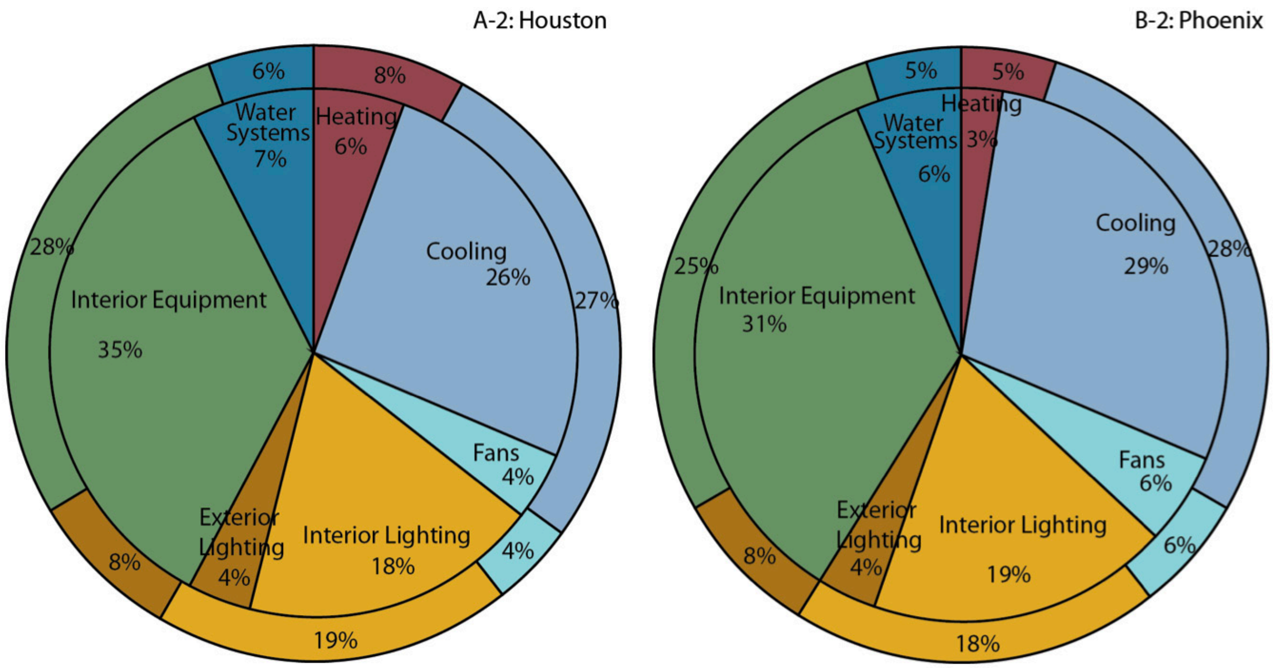


Figure B-5: Zone 2 relative site energy end use profiles for 2004 (outside) and 2010 (inside)

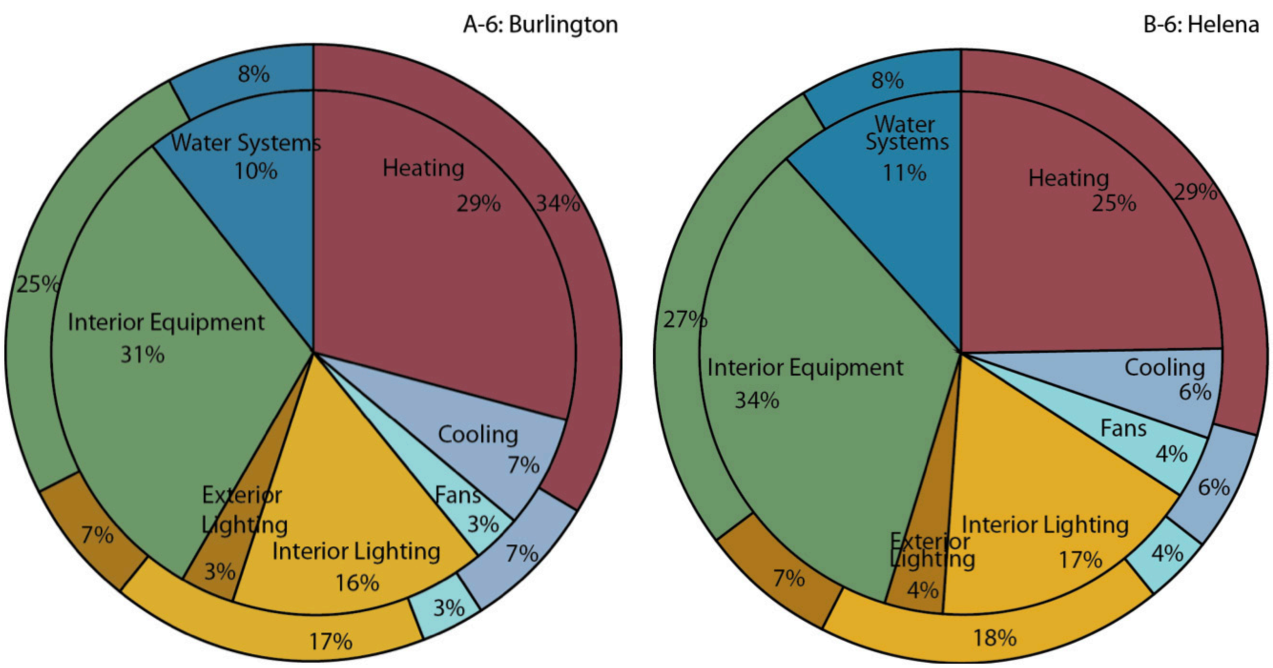


Figure B-6: Zone A6 and B6 relative site energy end use profiles for 2004 (outside) and 2010 (inside)

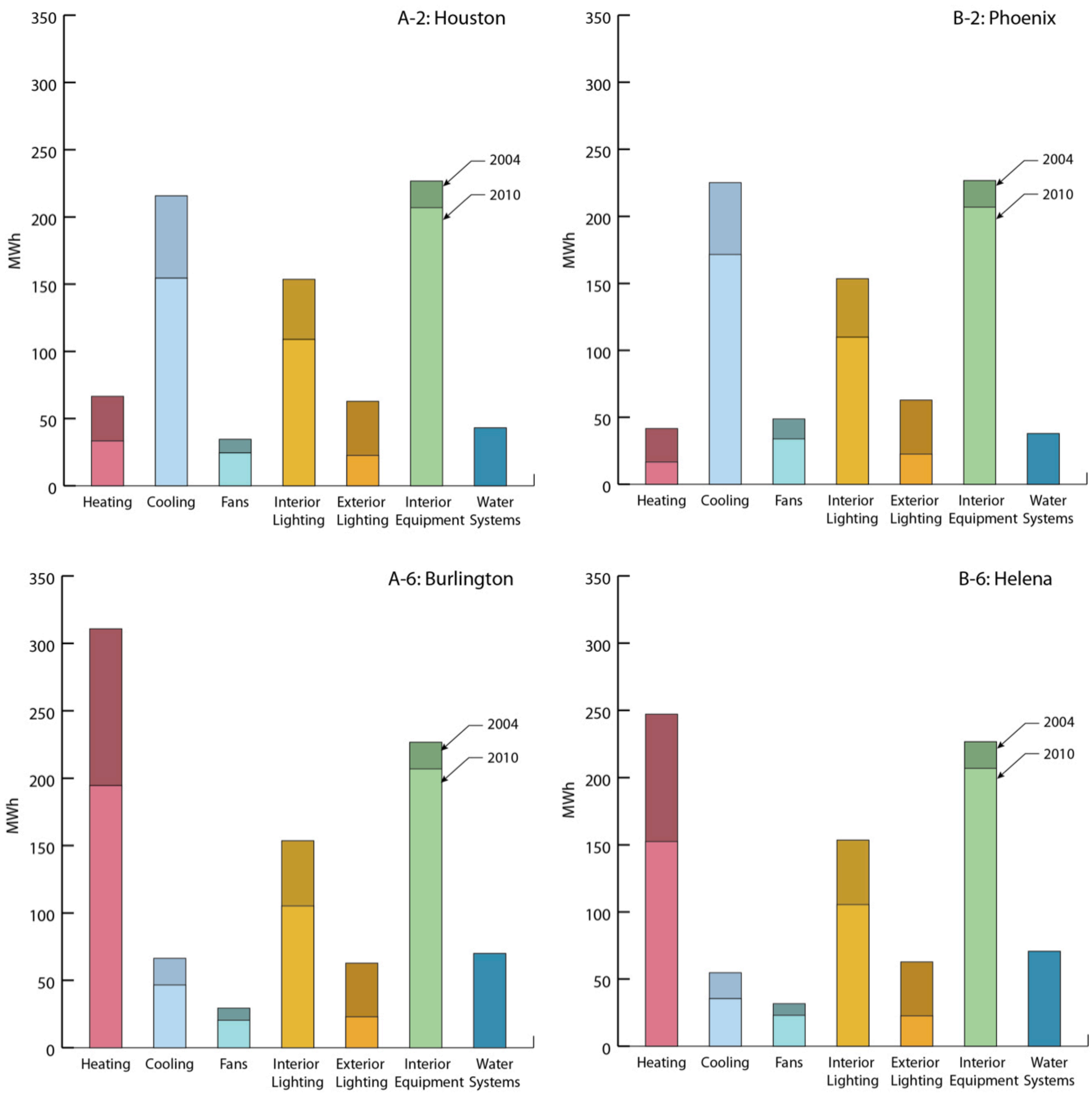


Figure B-7: Bar charts showing absolute site energy end-use profiles for 2004 (dark) and 2010 (light)

Figure B-8 shows only 90.1–2010 results across zones A 1-7 and B 2-6. The sizes of these pies do not correspond to total energy use; these pie charts are for comparisons of the end use percentages across zones. Here it is interesting to note the differing portion heating and cooling play across the zones, while fan use remains pretty constant.

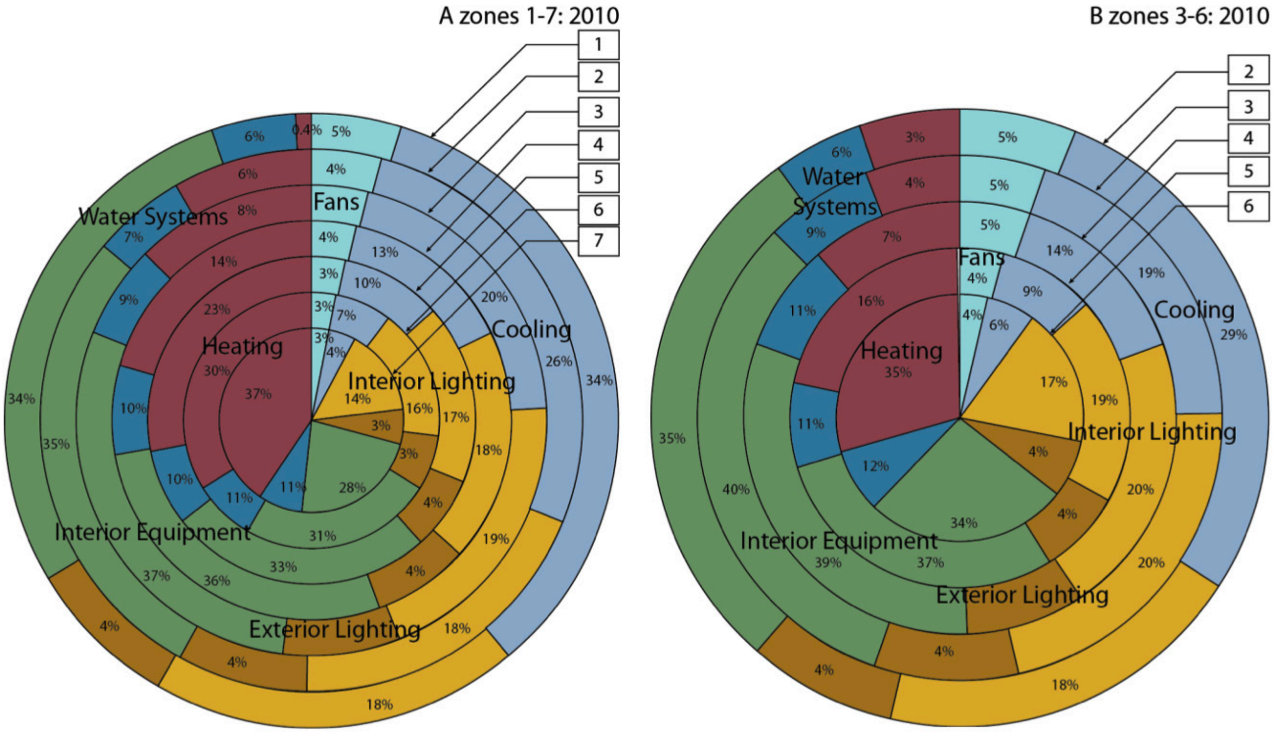


Figure B-8: 2010 site energy end-use profiles for all zones in A and B

B-3 Refined Simulation Results for Standard 90.1-2004 and 90.1-2010

The early analysis presented above has used the original PNNL models to generate the 90.1-2004 EUIs. Conversely, the results presented in the rest of this Appendix use the files as modified by SuPerB to use the 90.1-2010 HVAC and lighting efficiency levels for all four energy performance levels being examined.

This allows for consistent comparisons of enclosure measures across four energy performance levels, for the same set of lighting and HVAC inputs.

However, a side impact is that any EUI results for 90.1-2004 contain substantially lower EUIs because of the use of the 2010 HVAC and Lighting. So the 2004 baseline EUIs that include 2010 lighting and HVAC systems should be reviewed with caution.

B-3.1 Comparison of Energy Performance Indices

Site Energy & Source Energy

Site Energy: kBTU /GSF/year calculated at the site does not take into account conversion losses by fuel before reaching the site.

- This site-based parameter does not account for the energy used to transport energy to the site or for the often-considerable energy conversion losses that can occur at an electrical utility plant.
- This metric may underestimate the amount of electrical energy used by a building compared with the energy used by fossil fuels, and may provide a competitive advantage to electricity as a fuel option.
- The various ASHRAE 30% and 50% advanced energy design guides use the site energy metric.

Source Energy: kBTU /GSF/year calculated considering the conversion and transportation cost of getting energy to the site.

- USGBC is proposing that in the planned 2012 version of LEED, simulations of building performance for LEED submittals will be required to list the source energy comparisons as part of the documentation submitted.5
- This metric may be considered a more balanced approach to fuels used by a building, since it considers a more complete set energy used to provide the energy to the building.

Use of site versus source energy can lead to different interpretations of the energy consumed by a building. To calculate the Source energy, PNNL calculated electricity at 3.167x site energy and natural gas at 1.084x site energy. In the cooling-dominated southern climate zones, more electricity is used for A/C, whereas more gas is used for heating in the northern zones. As such, the source figures appear more advantageous buildings in the north, and the site number more advantageous to buildings in the south.

If a designer is trying to reduce total energy use, the use of source energy will give more weight to decisions reducing electricity while use of site energy will give more weight to natural gas. Thus, the sequence and priority of design decisions can change depending on the metric being used.

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5 LEED 2012, *LEED Rating System, 2nd Public Comment Draft, Building Design & Construction*, Includes:New Construction, Core & Shell, Schools, Retail, Data Centers, Warehouse & Distribution Centers, Hospitality, Healthcare, pp. 81-88, July 2011.

Table B-5: Site Energy Compared with Source Energy

Annual Energy Per Gross Floor Area [kBTU/GSF/year]	Site	Source
1(A) Miami	38.3	117.7
2(A) Houston	36.6	111.5
4(A) Baltimore	36.4	107.7
6(A) Burlington	41.4	114.9
2(B) Phoenix	37.7	115.9
4(B) Albuquerque	33.5	100.2
6(B) Helena	37.9	106.3
Percent Savings from Base (Base used) --->	CZ 4(B) Albuquerque	CZ 4(B) Albuquerque
1(A) Miami	14%	17%
2(A) Houston	9%	11%
4(A) Baltimore	9%	7%
6(A) Burlington	24%	15%
2(B) Phoenix	13%	16%
4(B) Albuquerque	0%	0%
6(B) Helena	13%	6%

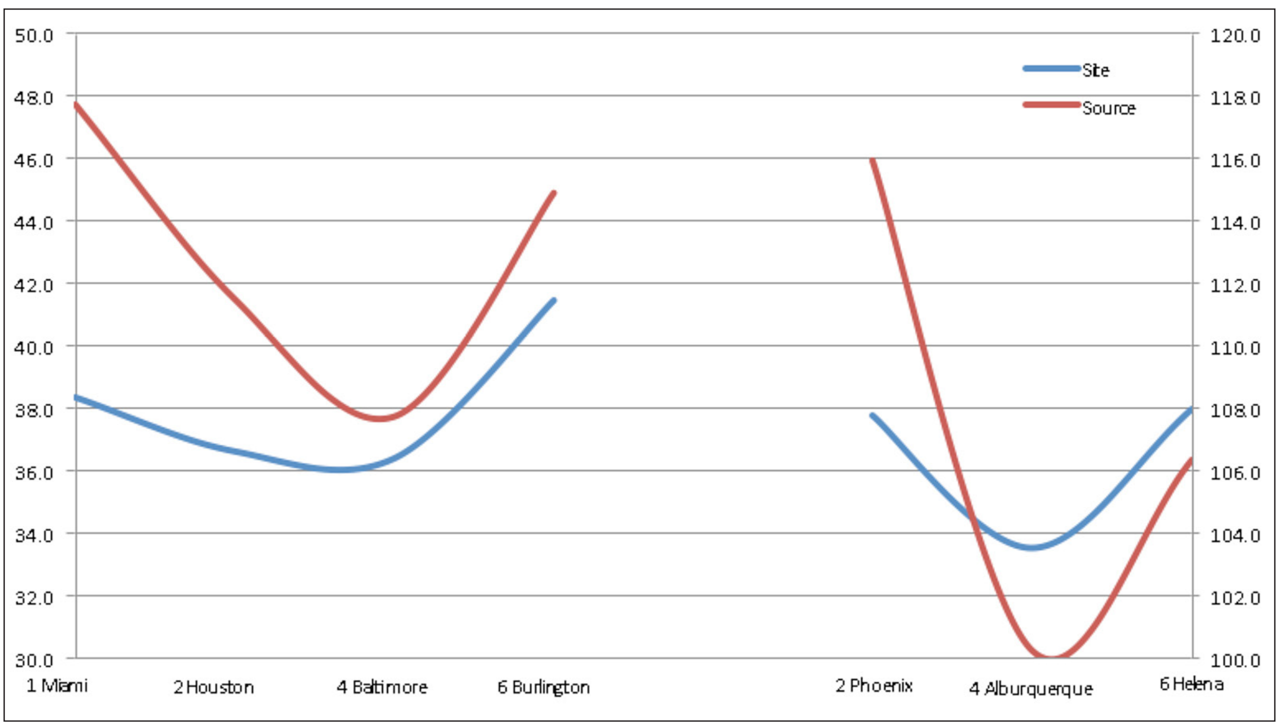

Figure B-9: EUI of Site vs Source energy

National Average Energy Cost

The 90.1 prescriptive requirements for all vintages to date have been developed using national average energy costs. Since we are examining whole building energy performance patterns rather than the prescriptive measures, we have not separately examined the patterns produced by those national average costs.

Local Energy Costs

Standard 90.1 whole-building energy performance uses local energy costs to compare the simulated performance of a proposed building design with a baseline building that precisely meets the prescriptive requirements of the 90.1 vintage being used. These local energy cost comparisons are used in Section 11, the Energy Cost Budget method, and in Appendix G, a Performance Rating Method. The local energy costs used in Section 11 and in Appendix G can vary substantially from the national average costs that are used in Sections 5, 6 and 7 of 90.1 for determining the enclosure, HVAC and SWH prescriptive requirements.

To demonstrate this potential variation, In our analysis below, state-level energy costs have been used to represent local energy costs. The State energy costs have been taken from:

- EIA, Electric Power Monthly, Natural Gas Prices, 8/2/2011 http://www.eia.gov/dnav/ng/ng_pri_sum_dcu_nus_m.htm
- EIA, Electric Power Monthly, 5.6 Average Retail Price of Electricity to Ultimate Customers by End-Use Sector, by State, July 20, 2011 http://www.eia.gov/cneaf/electricity/epm/epm_sum.html

Table B-6: Site Energy EUIs plus, Cost per GSF EUI for the 90.1-2010 P+ Benchmark, including prescriptive daylighting requirements Various Site Energy EUIs plus, Cost per GSF EUI.

Location	Electricity Consumption (kBtu/GSF)	Natural Gas Consumption (kBtu/GSF)	Electricity (cents/kWh)	Natural Gas ($/tcf)	Total Annual Cost per GSF
Miami, FL	36.1	2.2	9.97	10.59	$1.08
Houston, TX	33.7	2.9	8.88	8.03	$0.90
Baltimore, MD	29.9	6.4	11.46	9.93	$1.07
Burlington, VT	30.3	11.2	13.98	11.82	$1.37
Phoenix, AZ	35.2	2.5	9.27	10.71	$ 0.98
Albuquerque. NM	28.9	4.6	8.45	7.55	$ 0.75
Helena, MT	28.8	9.1	9.09	8.56	$ 0.84

Figure B-10: 90.1-2010 (with Daylighting), EUI of annual energy cost per GSF

B-4 Simulation Results for Non-Fenestration Enclosure Measures

B-4.1 General Enclosure Measures – 90.1-2004 to 90.1-2010

Such measures apply to the entire building enclosure. One measure we have simulated included reduced infiltration due to use of a continuous air barrier: 0.2 cfm/ft² and 0.1 cfm/ft².

Continuous Air Barriers were not required by ASHRAE 90.1-2004 In the PB baseline case but were required by ASHRAE 90.1-2010 for the P+ case. The PNNL reference buildings included reduced infiltration rates for 2010 compared to 2004. The whole building energy conservation percent reduction estimated by the EnergyPlus simulation from the 2004 PB baseline to the 2010 P+ level is shown below in Table B- 7.

Table B-8: Percent Reduction for reduced infiltration

	Site Energy
Percent Savings from PB Baseline of 90.1-2004	P+
1(A) Miami	0.3%
2(A) Houston	0.5%
4(A) Baltimore	2.3%
6(A) Burlington	3.7%
2 (B) Phoenix	0.4%
4(B) Albuquerque	1.2%
6(B) Helena	2.2%

The percent reduction in whole building energy use from the reduced infiltration is from 0.3% to 3.7% for the P+ level, where substantially more energy savings occur in the colder climates. While additional savings can be anticipated from further reductions in infiltration levels, In Phase 1 we did not simulate additional savings from any further reductions in infiltration beyond those required by the 90.1-2010 prescriptive requirements.

Table B-8: Improvements in infiltration from 90.1-2010 prescriptive requirements and comparison to adding 90.1-2010 prescriptive daylighting requirements (Baseline is 90.1-2004 no DL, Site Energy)

Energy Per Building Area [kBTU/GSF/yr]	2010 Ltg& HVAC 2004 Env Base	2010 Ltg& HVAC 2004 Env Base w/2010 Infiltration	2010 Ltg& HVAC 2004 Env Base w/ 2010 DL	Full 2010 Model
1(A) Miami	40.5	40.4	38.6	38.3
2(A) Houston	38.8	38.6	37.1	36.6
4(A) Baltimore	39.9	39.0	38.5	36.4
6(A) Burlington	45.2	43.5	44.1	41.4
2(B) Phoenix	40.1	39.9	38.2	37.7
4(B) Albuquerque	36.3	35.9	34.8	33.5
6(B) Helena	41.0	40.1	39.9	37.9
Percent Savings from Base (Base used) —>		**2004 w/ Infiltration** 2010 Ltg& HVAC 2004 Env Base	**2004 (w/DL)** 2010 Ltg& HVAC 2004 Env Base	**2010 (Basic DL)** 2010 Ltg& HVAC 2004 Env Base
1(A) Miami		0.3%	4.8%	5.5%
2(A) Houston		0.5%	4.5%	5.8%
4(A) Baltimore		2.3%	3.5%	8.9%
6(A) Burlington		3.7%	2.5%	8.3%
2(B) Phoenix		0.4%	4.5%	5.8%
4(B) Albuquerque		1.2%	4.2%	7.8%
6(B) Helena		2.2%	2.7%	7.4%

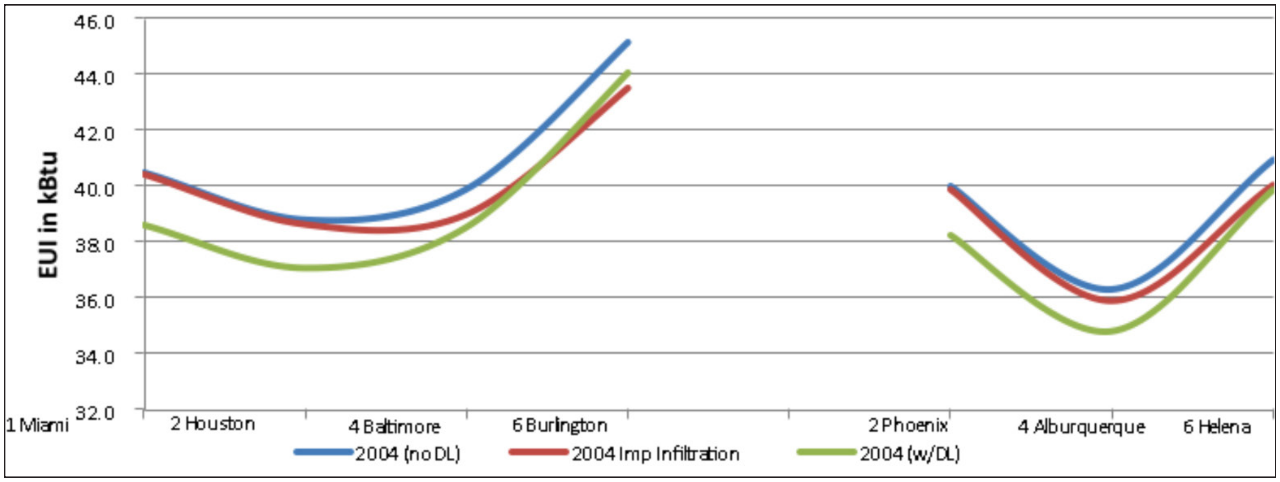

Figure B-11: Line graph of Site Energy EUI for 2004 Baseline, Baseline with infiltration rates from 90.1-2010 continuous air barrier prescriptive requirements, and Baseline with 90.1-2010 prescriptive daylighting requirements.

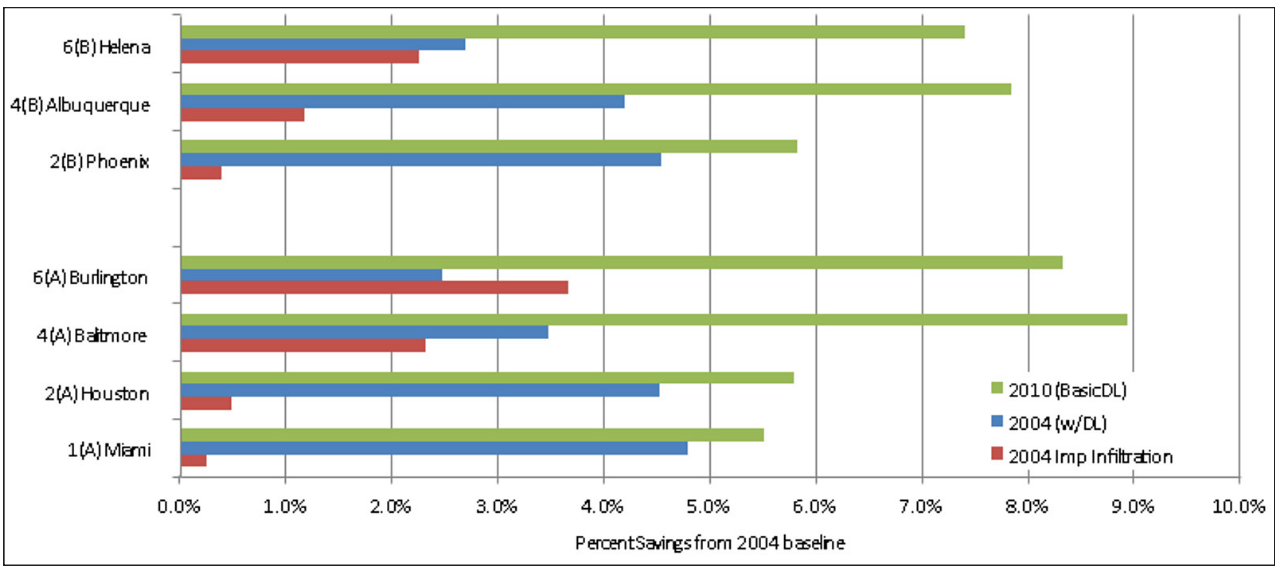

Figure B-12: Bar graph of Site Energy Percent Savings over 2004 Baseline for Baseline with Baseline with infiltration rates from 90.1-2010 continuous air barrier prescriptive requirements, and Baseline with 90.1-2010 prescriptive daylighting requirements.

In these infiltration graphs, we compare the improved infiltration rates from the 90.1-2010 prescriptive requirements for continuous air barriers with the 2004 baseline with the 2004 baseline with the 90.1-2010 prescriptive requirements in lighting section 9 for daylighting controls added.

As can be seen in the graph, reduced infiltration rates from the 90.1-2010 prescriptive requirements for continuous air barriers has a minor effect in the southern climate zones, and large effect in the northern zones. Adding the 90.1-2010 prescriptive requirements in lighting section 9 for daylighting controls to the building shows the opposite pattern and in the EUI graph, the lines cross one another in the northern zones. The 2010 figures have improved infiltration rates, daylighting controls, and miscellaneous other enclosure improvements required by the 90.1-2010 enclosure prescriptive requirements.

Table B-9: Improvements in infiltration from 90.1-2010 prescriptive requirements and comparison to adding 90.1-2010 prescriptive daylighting requirements (Baseline is 90.1-2004 no DL, Source Energy)

Energy Per Building Area [kBTU/ft^2]	2010 Ltg& HVAC 2004 Env Base	2010 Ltg& HVAC 2004 Env Base w/2010 Infiltration	2010 Ltg& HVAC 2004 Env Base w/ 2010 DL	Full 2010 Model
1(A) Miami	123.9	123.5	117.7	116.8
2(A) Houston	117.1	116.5	111.5	109.9
4(A) Baltimore	112.4	109.9	107.7	101.8
6(A) Burlington	118.9	114.7	114.9	107.9
2(B) Phoenix	121.7	121.2	115.9	114.3
4(B) Albuquerque	105.2	104.1	100.2	96.5
6(B) Helena	110.3	107.9	106.3	101.2
Percent Savings from Base (Base used) —>		**2004 w/ Infiltration** 2010 Ltg& HVAC 2004 Env Base	**2004 (w/DL)** 2010 Ltg& HVAC 2004 Env Base	**2010 (Basic DL)** 2010 Ltg& HVAC 2004 Env Base
1(A) Miami		0.3%	5.0%	5.7%
2(A) Houston		0.5%	4.8%	6.1%
4(A) Baltimore		2.1%	4.1%	9.4%
6(A) Burlington		3.5%	3.4%	9.2%
2(B) Phoenix		0.4%	4.8%	6.1%
4(B) Albuquerque		1.1%	4.8%	8.3%
6(B) Helena		2.2%	3.6%	8.3%

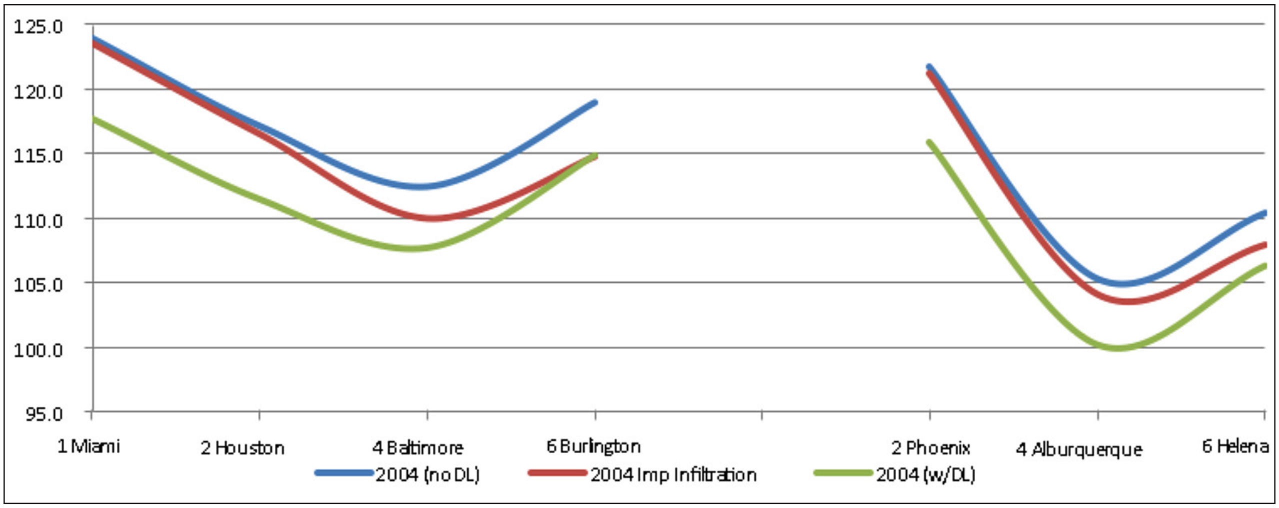

Figure B-13: Line graph of Source Energy EUI for 2004 Baseline, for Baseline with with infiltration rates from 90.1-2010 continuous air barrier prescriptive requirements, and Baseline with 90.1-2010 prescriptive daylighting requirements.

Note: in Figures B-13 and B - 14, (1) the red line with the label "2004 Infiltration" refers to the 2004 baseline with the 2010 prescriptive requirements for continuous air barriers added, and (2) the green line with the label "2004 (w/DL)" refers to the 2004 baseline with the 2010 prescriptive requirements in lighting section 9 for daylighting controls added.

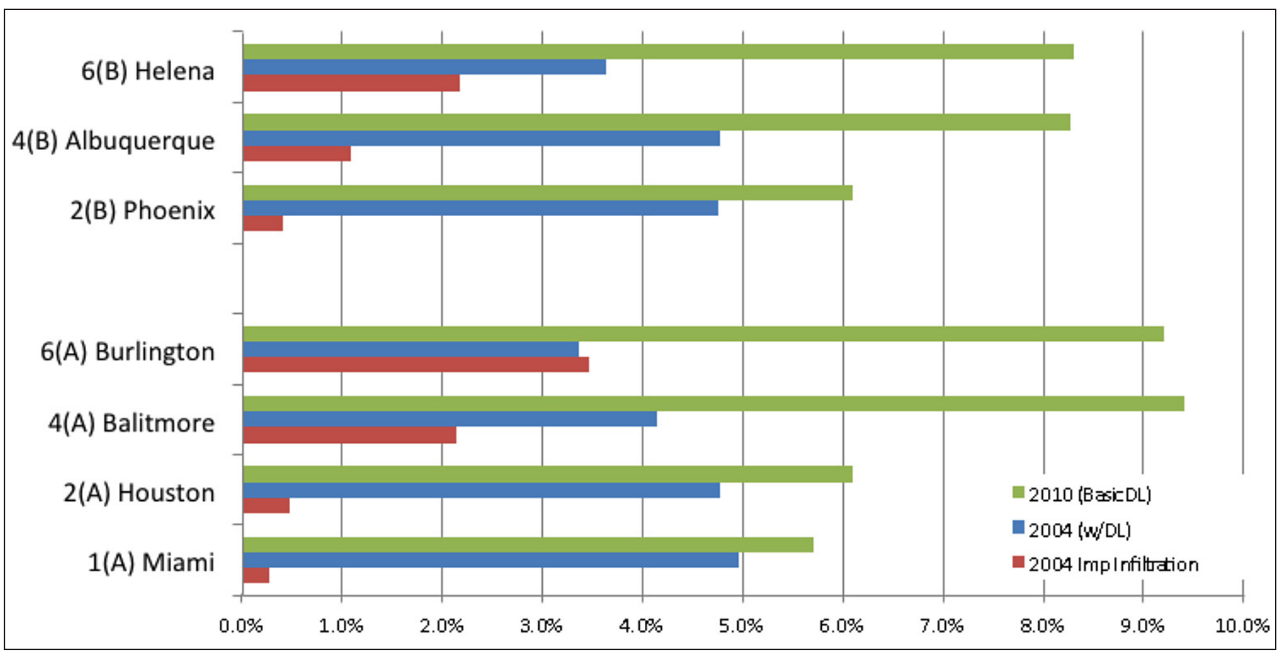

Figure B-14: Bar graph of Source Energy Percent Savings over 2004 Baseline for Baseline with improved infiltration rates and Baseline with daylighting controls

B-4.2 Opaque Enclosure Measures

The proposed HPBDE thermal performance target levels for increased insulation for the P+, P++, and HP levels are shown in Table B-9 below. Such measures apply just to the opaque portions of the building enclosure. The measures we have examined include:

- Increased wall insulation, relative to 90.1-2010.
- Increased roof insulation, relative to 90.1-2010.

There appear to be diminishing returns from already high levels of roof and wall insulation in the simulation results indicated below.

Table B-10: Building opaque wall and roof U-Factor thermal performance criteria

	U-Factor (Btu/ft2°F hr)			
Climate Zones	*Baseline (PB)*	*(P+) Improved*	*(P++) Enhanced*	*(HP) High Perf.*
Roofs CZ 1 ,2 &3	0.063	0.048	0.039	0.017
Roofs CZ 4, 5 & 6	0.063	0.048	0.032	0.017
Roofs CZ 7 & 8	0.048	0.048	0.028	0.017
	U-Factor (Btu/ft2°F hr)			
Climate Zones	*Baseline (PB)*	*(P+) Improved*	*(P++) Enhanced*	*(HP) High Perf.*
Walls CZ 1,2 & 3	0.124	0.084	0.064	0.023
Walls CZ 4, 5 & 6	0.084	0.064	0.037	0.023
Walls CZ 7 & 8	0.057	0.045	0.037	0.023

Note: the columns in Table B-11 the results for “Roof & Wall (P++)” and for “Roof & Wall (HP)” are based on the incremental to the results for “2010 (Basic DL).” Thus, only modest redvuctions in whole-building energy conservation resulted from the additional levels of roof and wall insulation. Also, the term “Basic DL” refers to daylighting solutions to meet the prescriptive requirements of 90.1-2010, Section 9 lighting controls for daylighting.

Compared to a baseline of 90.1-2010 (with prescriptive daylighting), a combined set of high performance roof and wall insulation produced the results shown in the tables and figures immediately below.

Table B-11: Percent Reduction for opaque wall and roof U-Factor

	Site Energy	
Percent Savings from P+ Base of 90.1-2010	P++	HP
1(A) Miami	1.1%	1.8%
2(A) Houston	1.6%	2.5%
4(A) Baltimore	1.8%	2.8%
6(A) Burlington	3.0%	4.8%
2 (B) Phoenix	2.0%	3.2%
4(B) Albuquerque	1.4%	2.1%
6(B) Helena	3.1%	4.9%

The percent reduction in whole building site energy use U-Factor criteria for opaque wall and roof combined is from 1.1% to 3.1% for the P++ criteria and from 1.8% to 4.9% for the HP criteria. There appear to be diminishing returns from the already high levels of roof and wall insulation shown for ASHRAE 90.1-2010 (P+). There also appear to be diminishing returns from already high levels of roof and wall insulation in the baseline condition.

Table B-12: High Performance Opaque Roof & Wall Performance: (Baseline for 90.1-2010 is 90.1-2004, no DL, Site Energy; Baseline for Added Roof & Wall Insulation is 90.1-2010)

Energy Per Gross Building Area [kBTU/GSF/yr]	2004 (No DL)	2004 (w/ DL)	2010 (Basic DL)	Roof & Wall (P++)	Roof & Wall (HP)
1(A) Miami	40.5	38.6	38.3	37.9	37.6
2(A) Houston	38.8	37.1	36.6	36.0	35.6
4(A) Baltimore	39.9	38.5	36.4	35.6	35.3
6(A) Burlington	45.2	44.1	41.4	40.1	39.3
2(B) Phoenix	40.1	38.2	37.7	36.9	36.5
4(B) Albuquerque	36.3	34.8	33.5	33.0	32.7
6(B) Helena	41.0	39.9	37.9	36.7	35.9
Percent Savings from Base	2004 (No DL)	2004 (w/ DL)	2010 (Basic DL)	Roof & Wall (P++)	Roof & Wall (HP)
(Base used) —>		2004 (No DL)	2004 (No DL)	2004 (No DL)	2004 (No DL)
1(A) Miami		4.8%	5.5%	6.6%	7.3%
2(A) Houston		4.5%	5.8%	7.4%	8.3%
4(A) Baltimore		3.5%	8.9%	10.7%	11.7%
6(A) Burlington		2.5%	8.3%	11.3%	13.1%
2(B) Phoenix		4.5%	5.8%	7.8%	9.0%
4(B) Albuquerque		4.2%	7.8%	9.2%	9.9%
6(B) Helena		2.7%	7.4%	10.5%	12.3%

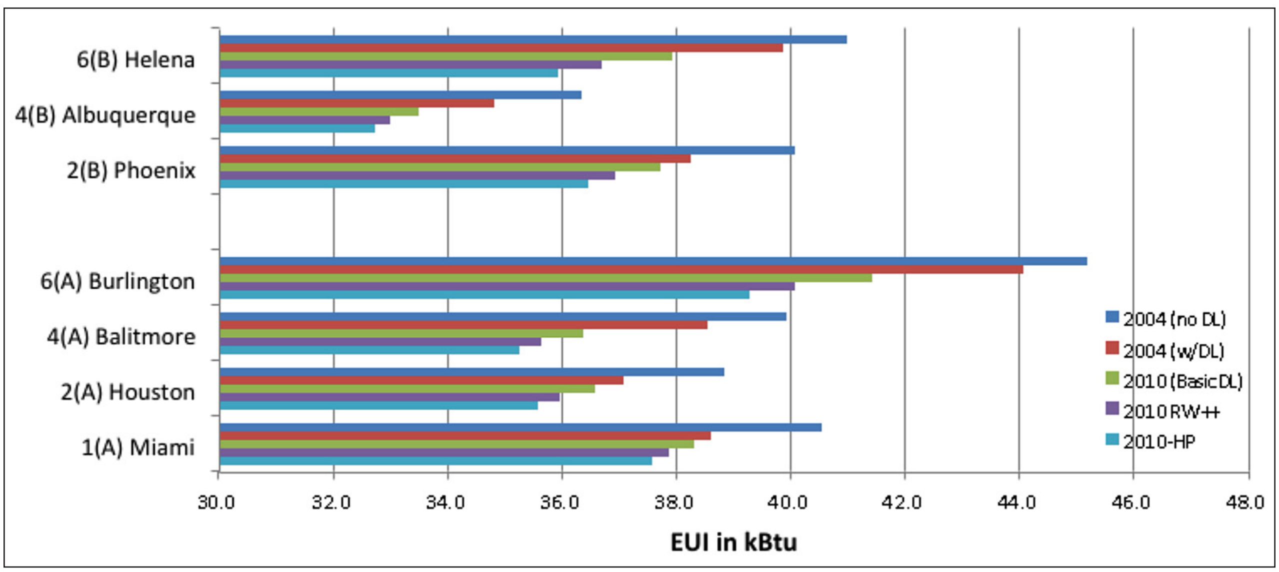

Figure B-15: Bar Graph of Site EUI for 2004 Baseline (Baseline for 90.1-2010 is 90.1-2004, no DL, Site Energy; Baseline for Added Roof & Wall Insulation is 90.1-2010)

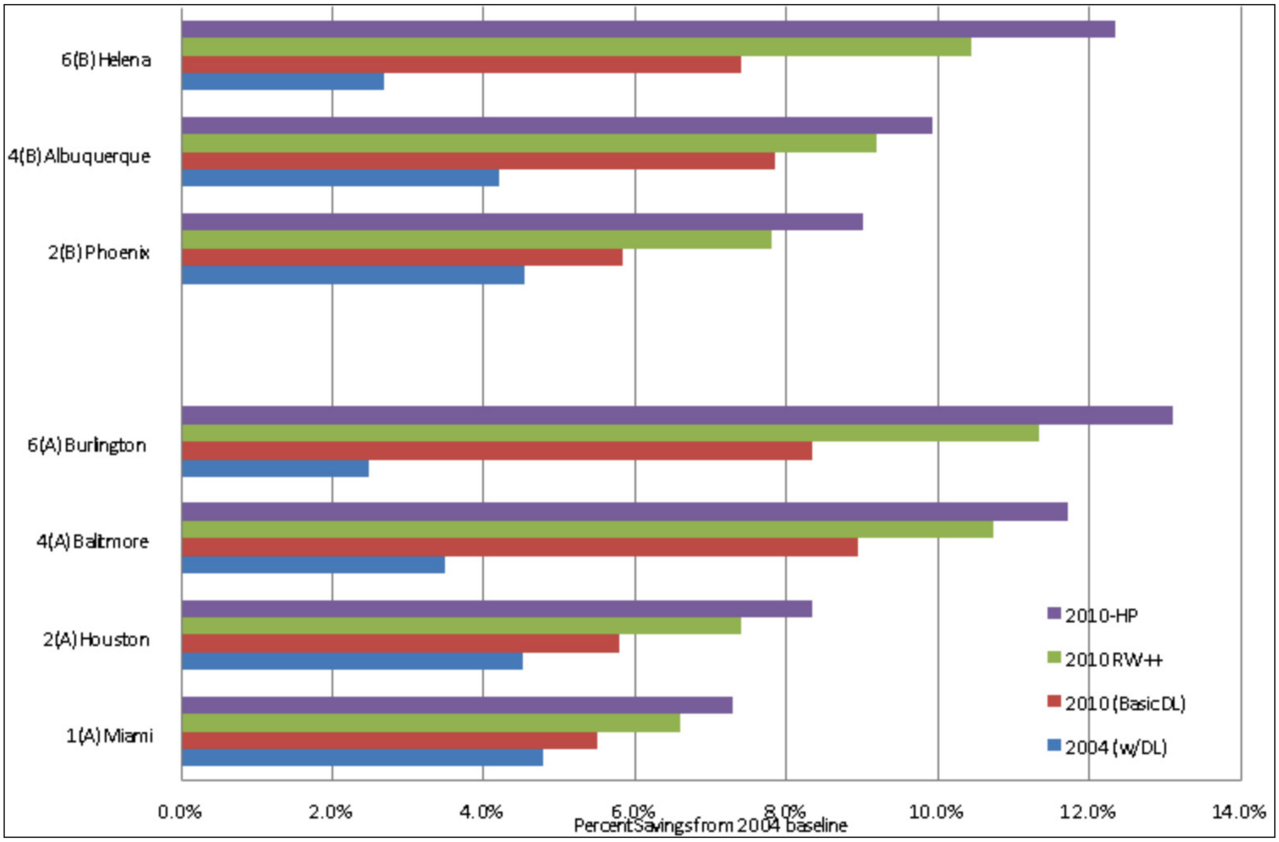

Figure B-16: Bar Graph of Site Energy Percent savings for each level of performance from 2004 Baseline

Table B-13: High Performance Opaque Roof & Wall Performance: (Baseline is 90.1-2004, no DL, Source Energy)

Energy Per Gross Building Area [kBTU/ft^2]	2004 (No DL)	2004 (w/ DL)	2010 (Basic DL)	2010 RW++	2010 HP
1(A) Miami	123.9	117.7	116.8	115.4	114.5
2(A) Houston	117.1	111.5	109.9	108.0	106.8
4(A) Baltimore	112.4	107.7	101.8	99.7	98.5
6(A) Burlington	118.9	114.9	107.9	104.4	102.1
2(B) Phoenix	121.7	115.9	114.3	111.8	110.3
4(B) Albuquerque	105.2	100.2	96.5	95.1	94.3
6(B) Helena	110.3	106.3	101.2	97.8	95.8
Percent Savings from Base (Base used) —>	**2004 (No DL)**	**2004 (w/ DL)** 2004 (No DL)	**2010 (Basic DL)** 2004 (No DL)	**2010 RW++** 2004 (No DL)	**2010 HP** 2004 (No DL)
1(A) Miami		5.0%	5.7%	6.8%	7.6%
2(A) Houston		4.8%	6.1%	7.8%	8.8%
4(A) Baltimore		4.1%	9.4%	11.2%	12.3%
6(A) Burlington		3.4%	9.2%	12.2%	14.1%
2(B) Phoenix		4.8%	6.1%	8.2%	9.4%
4(B) Albuquerque		4.8%	8.3%	9.6%	10.3%
6(B) Helena		3.6%	8.3%	11.3%	13.2%

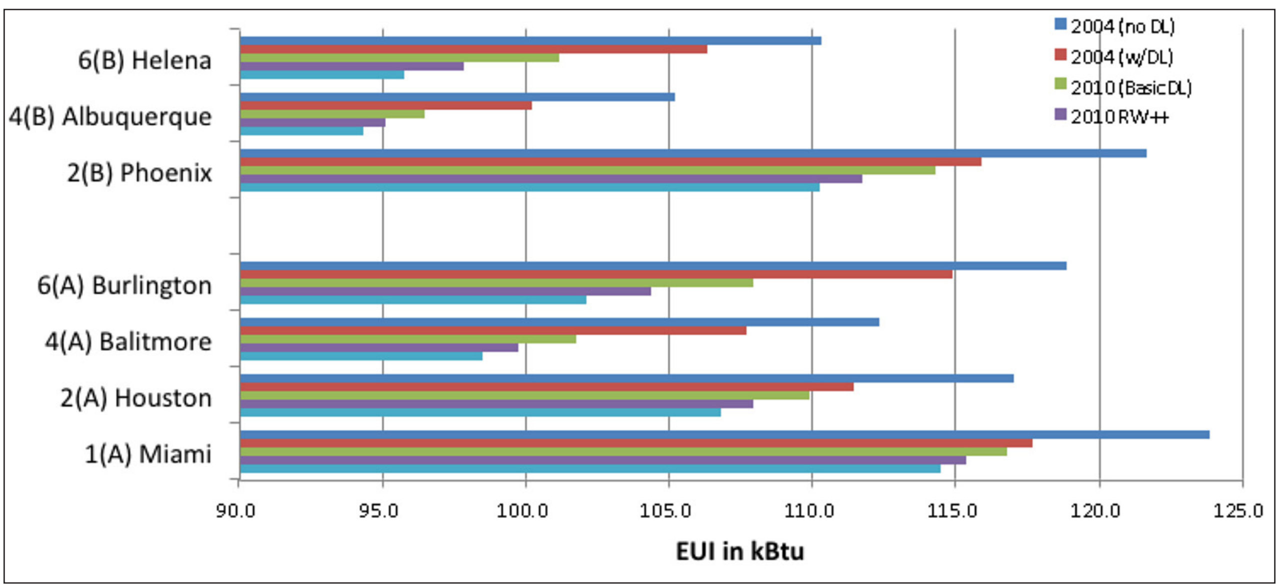

Figure B-17: Bar Graph of Source Energy EUI for 2004 Baseline, Baseline plus daylighting, 2010, and two levels of 2010 plus roof and wall envelop improvements

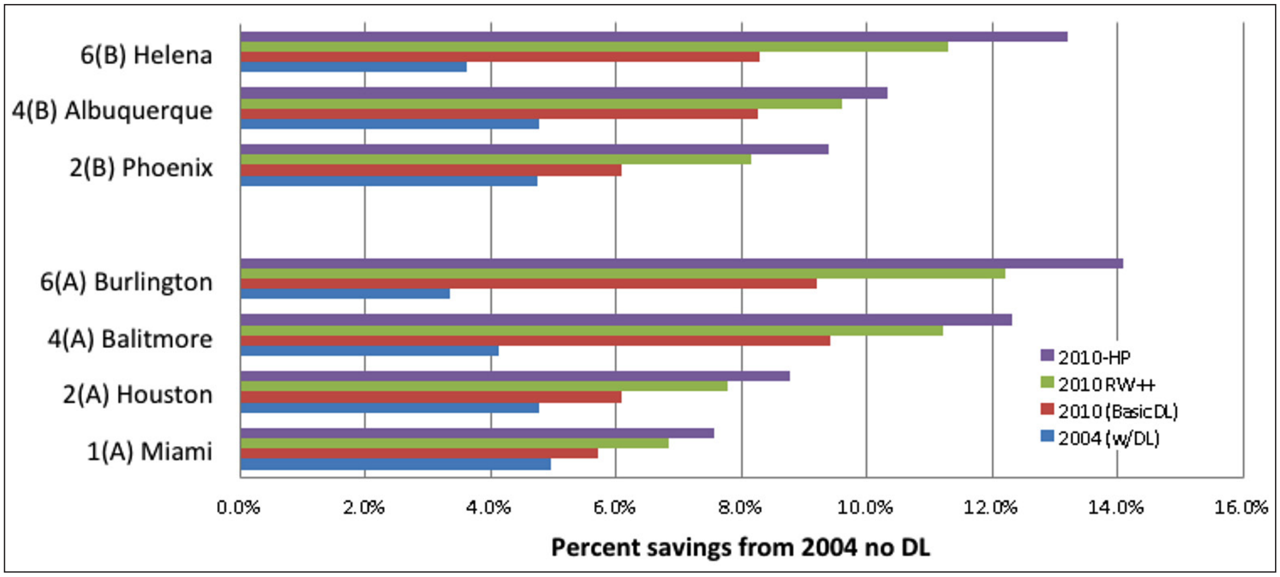

Figure B-18: Bar Graph of Source Percent savings for each level of performance from 2004 Baseline

B-4.3 Limited Analysis of Natural Ventilation

Due to modeling complexities, the approach precluded the development of simulations to measure the performance of natural ventilation. As a result, expert predictions by members of the fenestration and architectural committees were utilized in this phase to identify the performance benefits as measured by energy cost savings and capital costs for employing natural ventilation until a further analysis can be conducted to simulate results. The cost predictions are contained in the OPR database and used by the OPR tool in cost-benefit analysis of scenarios. These predictions are in very general qualitative terms and do not include quantitative estimates of energy consumption. We have identified EnergyPlus files that address natural and hybrid ventilation that are the result of research conducted at LBNL. We have requested the files but have not yet obtained them.[6]

6 Verbal communications with Philip Haves, Director of Simulation Group, LBNL.

B-5 Thermal Performance Targets for Fenestration

B-5.1 U-Factor performance criteria for building fenestration

Table B-14 below shows the U-Factor criteria for the fenestration assembly (center of glass, edge of glass, and frame). The U-Factor criteria improve with each performance level. In climates zones 1 through 6, the improvement in U-Factor thermal performance level from the (PB) Baseline of 90.1-2004 to the (HP) High Performance case is about 40%. In climate zones 6 and 7, the Enhanced and High Performance thermal performance levels propose substantial improvements in fenestration U-Factor performance via the use of the highest performance fenestration assemblies available. The HP High Performance thermal performance case assumes the use of a quadruple pane glazing system with a U-Factor of 0.10.

Table B-14: Building fenestration U-Factor criteria

	U-Factor (Btu/ft2°F hr)			
Climate Zones	*Baseline (PB)*	*(P+) Improved*	*(P++) Enhanced*	*(HP) High Perf.*
CZ 1, 2, & 3	0.70	0.60	0.50	0.40
CZ 4, 5 & 6	0.40	0.35	0.30	0.25
CZ 7 & 8	0.35	0.20	0.15	0.10

B-5.2 SHGC thermal performance criteria for the fenestration assembly only

Table B-15 below in this section includes the SHGC thermal performance criteria for the fenestration assembly (center of glass, edge of glass, and frame) for the fenestration only. No external, integral, or internal shading devices are considered.

The effects of SHGC are currently assessed indirectly in the OPR model that is part of this overall Phase 1 project effort, but SHGC is not directly included. The evaluations that we are doing of variations in SHGC provide useful information to provide a basis for adding SHGC more directly into the OPR tools in subsequent phases of this project.

The thermal performance SHGC criteria for the fenestration assemblies propose no increase in performance from (P+) Improved to (P++) Enhanced or even to (HP) High Performance. This lack of improvement in performance criteria assumes that we are close to the current technical limit for the criteria for the near future.

Table B-15: SHGC thermal performance criteria for fenestration assembly only

	SHGC (for fenestration Assembly only)			
Climate Zones	*Baseline (PB)*	*(P+) Improved*	*(P++) Enhanced*	*(P++) High Perf.*
CZ 1, 2, & 3	0.25	0.25	0.25	0.25
CZ 4, 5 & 6	0.47	0.40	0.40	0.40
CZ 7 & 8	NR	0.45	0.45	0.45

B-5.3 SHGC thermal performance criteria for the fenestration plus external fixed shades

Table B-16 below in this section includes the SHGC criteria for the fenestration assembly (center of glass, edge of glass, and frame) for the fenestration, as modified by the applicable external, integral, or internal fixed shading devices.

Table B-16: SHGC thermal performance criteria for fenestration assembly plus fixed External Shades (Overhangs)

	SHGC (for fenestration Assembly plus External Fixed Shades)			
Climate Zones	*Baseline (PB)*	*(P+) Improved*	*(P++) Enhanced*	*(P++) High Perf.*
CZ 1, 2, & 3	0.25	0.225	0.2	0.175
CZ 4, 5 & 6	0.47	0.39	0.38	0.37
CZ 7 & 8	NR	0.45	0.45	0.45

In the cooling-dominated Climate Zones 1, 2, and 3, a 20% improvement in thermal performance from the PB Baseline is projected for the P++ Enhanced Performance level, and a 30% improvement in thermal performance is projected for the HP High Performance level. These seem quite reasonable given that ASHRAE 90.1-2010 provides a 0.67 SHGC multiplier (33% improvement in performance) for a projection factor of 0.40.

B-5.4 SHGC criteria for the fenestration plus external dynamic shading devices

Table B-17 below in this section includes the SHGC criteria for the fenestration assembly (center of glass, edge of glass, and frame) for the fenestration, as modified by the impact of applicable external, integral, or internal dynamic shading devices. Dynamic shades are anticipated to have more benefit than fixed shades.

Table B-17: SHGC thermal performance criteria for fenestration assembly plus dynamic External Shades (Overhangs)

	SHGC (for fenestration Assembly plus Dynamic Shades)			
Climate Zones	*Baseline (PB)*	*(P+) Improved*	*(P++) Enhanced*	*(P++) High Perf.*
CZ 1, 2, & 3	0.25	0.2	0.16	0.14
CZ 4, 5 & 6	0.47	0.3	0.27	0.24
CZ 7 & 8	NR	0.4	0.39	0.38

B-6 Simulation Results for Fenestration Measures

B-6.1 High Performance Double Pane Windows

In these analyses we repeat the results for high performance roof and wall measures and add simulation results for two advanced double pane windows, one of which is used in cooling climates and the other in heating climates. For convenience in comparing window properties with energy performance, we repeat several columns from the data in Table B-3 below as Table B-18. The table below compares the high performance double pane windows with the baseline windows.

Compared with the baseline windows: the two high performance double pane windows have:

- U-Factors that are significantly lower.
- Tvis values that are much higher in the cooling climates and slightly higher in the heating climates. All other things being equal, this improves daylight performance.
- SHGC values that are the same as the baseline in the cooling climates, and just slightly lower in the heating climates.

Table B-18: Selected High Performance Double Pane Windows,from a baseline of 90.1-2004 and 90.1-2010

	Base(2004 & 2010)	Advanced Double Pane (High VT)
CZ 1,2,3		
U Value	0.56	0.36
SHGC	0.25	0.25
Tvis	0.35	0.57
CZ 4,5,6		
U Value	0.47	0.35
SHGC	0.39	0.35
Tvis	0.60	0.62

Table B-19: Individual and Bundled Site Energy (EUI) Performances with improved Roof and Wall,and with Double pane Windows: (Baseline is 90.1-2010 with DL, Site Energy)

Energy Per Building Area [kBTU/ft^2]	2010 (Basic DL)	2010 Roof++	2010 Walls++	2010 RW++	2010 RW++ &AdvDoublePane	2010 Roof	2010 HP Walls	2010 HP RW	2010 HP RW &AdvDoublePane
1(A) Miami	38.3	38.2	38.0	37.9	37.8	38.1	37.8	37.6	37.6
2(A) Houston	36.6	36.4	36.1	36.0	35.4	36.3	35.8	35.6	35.2
4(A) Baltimore	36.4	36.1	36.0	35.6	34.6	35.8	35.7	35.3	34.4
6(A) Burlington	41.4	40.8	40.6	40.1	37.6	40.4	40.3	39.3	37.1
2(B) Phoenix	37.7	37.6	37.1	36.9	36.3	37.4	36.7	36.5	35.9
4(B) Albuquerque	33.5	33.2	33.2	33.0	32.6	33.0	33.1	32.7	32.5
6(B) Helena	37.9	37.4	37.2	36.7	34.6	36.9	36.9	35.9	34.2
Percent Savings from Base (Base used) —>	2010 (Basic DL)	2010 Roof++ 2010 (w/DL)	2010 Walls++ 2010 (w/DL)	2010 RW++ 2010 (w/DL)	2010 RW++ &AdvDoublePane 2010 (w/DL)	2010 Roof 2010 (w/DL)	2010 HP Walls 2010 (w/DL)	2010 HP RW 2010 (w/DL)	2010 HP RW+ &AdvDoublePane 2010 (w/DL)
1(A) Miami		0.3%	0.9%	1.1%	1.3%	0.5%	1.4%	1.9%	1.9%
2(A) Houston		0.4%	1.3%	1.7%	3.3%	0.8%	2.1%	2.7%	3.8%
4(A) Baltimore		0.8%	1.1%	2.0%	4.9%	1.6%	1.7%	3.0%	5.5%
6(A) Burlington		1.4%	2.0%	3.3%	9.2%	2.5%	2.8%	5.2%	10.5%
2(B) Phoenix		0.4%	1.7%	2.1%	3.9%	0.8%	2.7%	3.4%	4.8%
4(B) Albuquerque		0.8%	0.8%	1.5%	2.7%	1.4%	1.1%	2.3%	2.9%
6(B) Helena		1.5%	1.9%	3.3%	8.8%	2.8%	2.7%	5.3%	9.9%

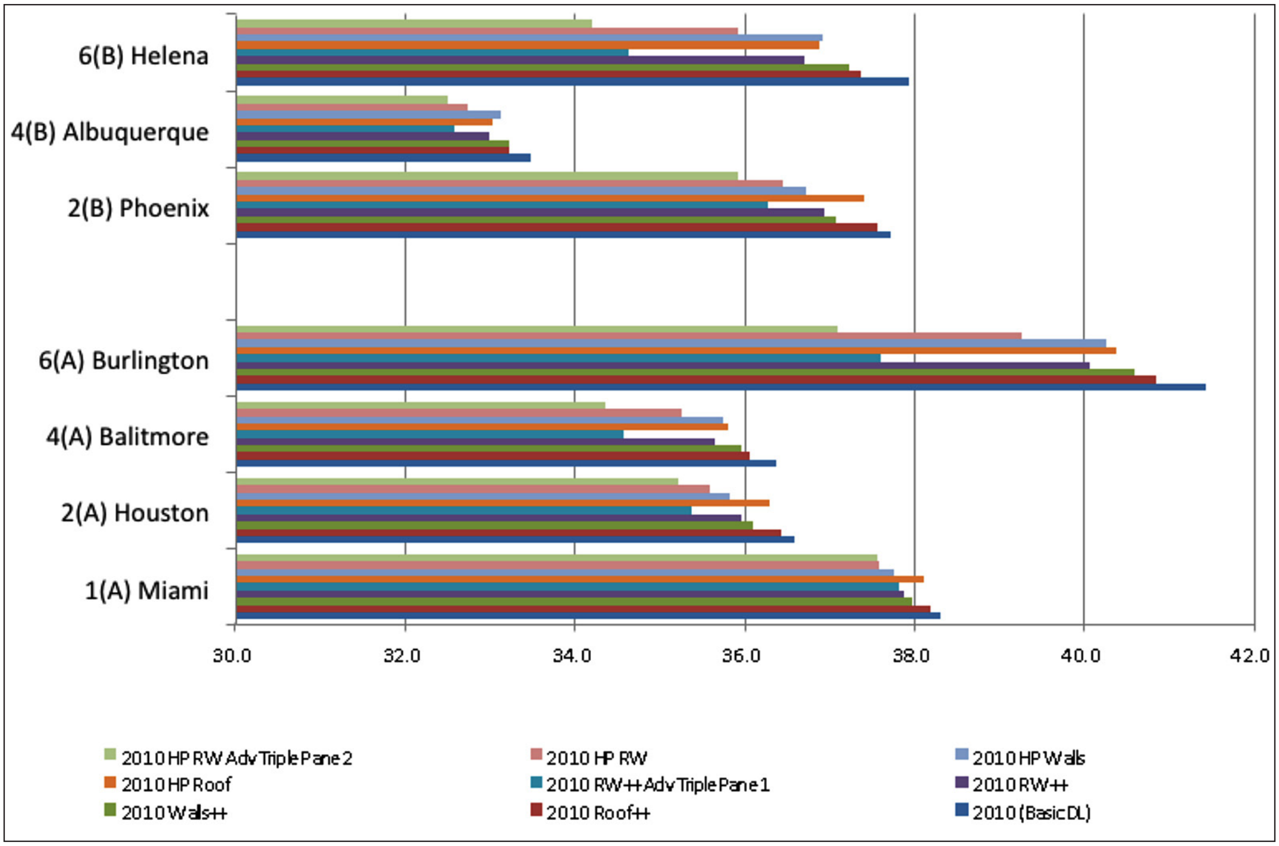

Figure B-19: Bar Graph of Individual and Bundled Site EUI Performances for 2010 with DL Baseline, 2010 with individual and combined roof and wall enclosure improvements, and improved double pane windows

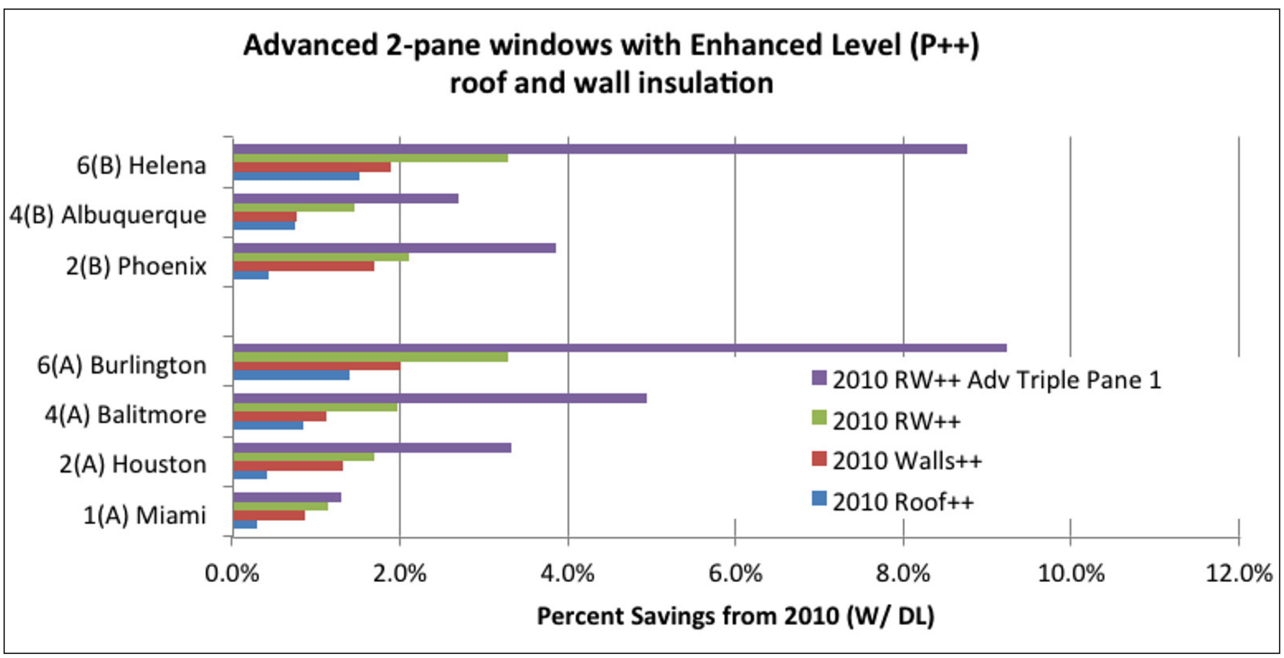

Figure B-20: Bar graph of Whole Building Site Energy Percent Savings for three P++ level enclosure improvements compared to P+ energy performance (i.e., 2010 with Prescriptive Daylighting Requirements)

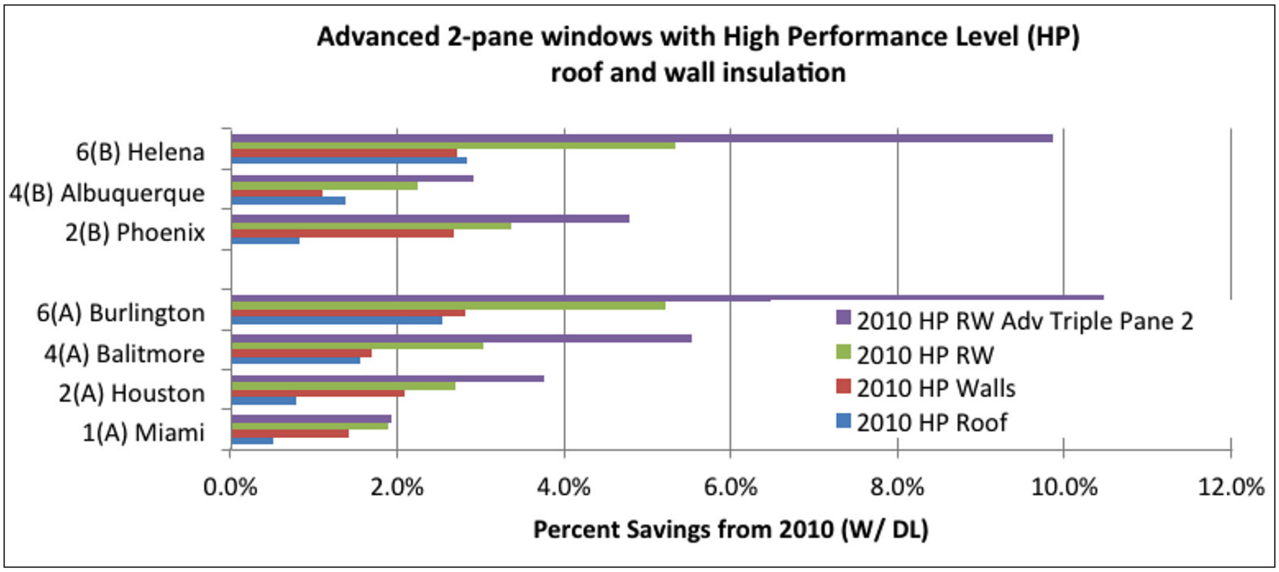

Figure B-21: Bar graph of Whole Building Site Energy Percent Savings for three HP level enclosure improvements compared to P+ energy performance (i.e., 2010 with Prescriptive Daylighting Requirements)

Opaque surfaces: For the simulations for both the P++ Enhanced and HP High Performance insulation levels, improving the wall insulation levels had a somewhat greater effect than increasing the roof insulation levels. This relative improvement would likely change as the buildings improving both wall and roof had a much stronger improvement than those improving just walls or roof separately.

High performance windows: Two double pane windows in these runs were chosen respectively for warmer and cooler climate zones. The window selected for the warmer climates has a very low SHGC (0.25), while the window selected for the cooler climates has a higher SHGC (0.35). You can see from the graphs that the use of these high performance windows produced dramatic savings in the northern zones, dwarfing the savings from improving the insulation levels.

Table B-20: Individual Performance of Advanced Roof and Wall measures, and with Advanced Double pane Windows (Baseline is 90.1-2010 with prescriptive DL requirements, Source Energy)

Energy Per Building Area [kBTU/ft^2]	2010 (Basic DL)	Better Roof (P++)	Better Walls (P++)	Better Roof & Walls (P++)	Roof & Walls & AdvDoublePane (P++)	Better Roof (HP)	Better Walls (HP)	Better Roof & Walls (HP)	Roof & Walls & AdvDoublePane (P++)
1(A) Miami	116.8	116.4	115.7	115.4	115.2	116.2	115.1	114.5	114.4
2(A) Houston	109.9	109.4	108.4	108.0	105.8	109.0	107.5	106.8	105.3
4(A) Baltimore	101.8	100.8	100.6	99.7	96.1	100.0	100.1	98.5	95.6
6(A) Burlington	107.9	106.4	105.8	104.4	97.2	105.0	104.9	102.1	95.8
2(B) Phoenix	114.3	113.7	112.2	111.8	109.7	113.3	111.1	110.3	108.6
4(B) Albuquerque	96.5	95.8	95.8	95.1	93.7	95.2	95.5	94.3	93.6
6(B) Helena	101.2	99.6	99.3	97.8	92.0	98.2	98.4	95.8	91.0
Percent Savings from Base (Base used) —>	2010 (Basic DL)	Better Roof (P++) 2010 (w/DL)	Better Walls (P++) 2010 (w/DL)	Better Roof & Walls (P++) 2010 (w/DL)	Roof & Walls & AdvDoublePane (P++) 2010 (w/DL)	Better Roof (HP) 2010 (w/DL)	Better Walls (HP) 2010 (w/DL)	Better Roof & Walls (HP) 2010 (w/DL)	Roof & Walls & AdvDoublePane (P++) 2010 (w/DL)
1(A) Miami		0.3%	0.9%	1.2%	1.4%	0.5%	1.5%	2.0%	2.0%
2(A) Houston		0.4%	1.4%	1.8%	3.7%	0.8%	2.2%	2.9%	4.2%
4(A) Baltimore		0.9%	1.1%	2.0%	5.5%	1.7%	1.7%	3.2%	6.1%
6(A) Burlington		1.4%	1.9%	3.3%	9.9%	2.7%	2.8%	5.4%	11.3%
2(B) Phoenix		0.5%	1.8%	2.2%	4.0%	0.9%	2.8%	3.5%	5.0%
4(B) Albuquerque		0.7%	0.8%	1.4%	2.9%	1.4%	1.1%	2.2%	3.0%
6(B) Helena		1.5%	1.9%	3.3%	9.1%	2.9%	2.7%	5.3%	10.1%

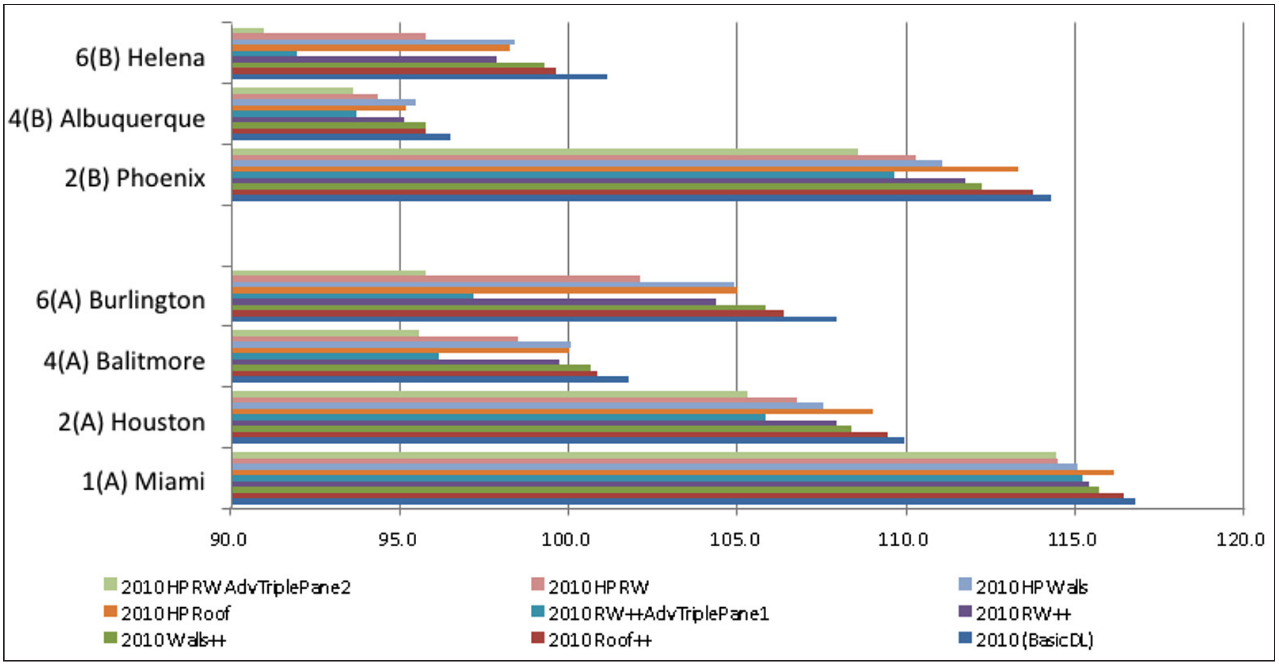

Figure B-22: Bar Graph of Individual and Combined Performance of Advanced Roof and Wall Measures, and with Advanced Double pane Windows (Baseline is 90.1-2010 with prescriptive DL requirements, Source Energy)

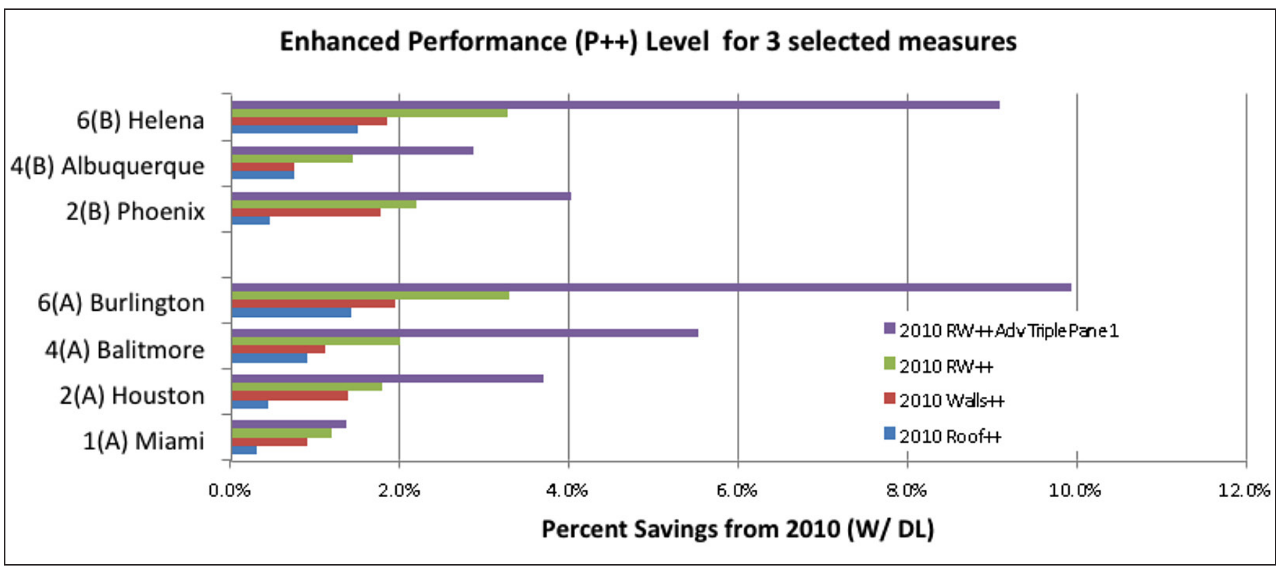

Figure B-23: Bar Graph of Source Percent Savings for Individual and Combined Performance of P++ Advanced Roof and Wall Measures, and with Advanced Double pane Windows (Baseline is 90.1-2010 with prescriptive DL requirements, Source Energy)

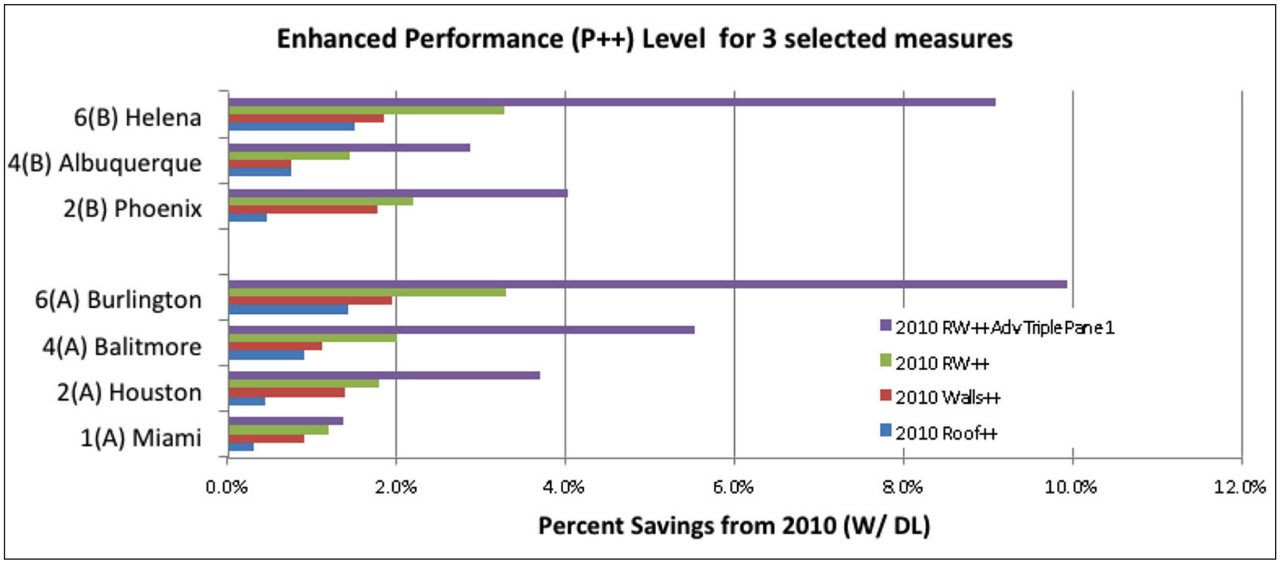

Figure B-24: Bar Graph of Source Percent Savings for Individual and Combined Performance of HP Advanced Roof and Wall Measures, and with Advanced Double pane Windows (Baseline is 90.1-2010 with prescriptive DL requirements, Source Energy)

B-6.2 Additional High Performance Window Options

In this section we examine the energy performance of several additional high performance window options including:

- Advanced double pane (also shown in previous section)
- Advanced triple pane
- Advanced quadruple pane

Simulation runs were performed examining electrochromic glazing, using glare controls and electrochromic glazing, using daylighting controls, but these control algorithms found in Energy Plus are not deemed to be reliable. As a result, these two schemes will not be presented here. Further studies integrating Energy Plus with more reliable controllers is needed to properly assess the impact of this technology.

Table B-21: Site Energy (EUI) Performances for Individual Advanced Window Measures (Baseline is 90.1-2010 with prescriptive DL requirements, Site Energy)

Energy Per Total Building Area [kBTU/ft^2]	2010 (Basic DL)	2010 20% WWR	Adv. Double Pane	Adv. Triple Pane 2	Quad Solar
1(A) Miami	38.3	37.1	37.1	38.9	37.0
2(A) Houston	36.6	35.4	35.0	36.2	34.9
4(A) Baltimore	36.4	35.5	35.0	34.8	34.8
6(A) Burlington	41.4	40.0	38.5	37.6	38.0
2(B) Phoenix	37.7	36.2	35.8	37.4	35.6
4(B) Albuquerque	33.5	32.6	32.8	33.0	32.3
6(B) Helena	37.9	36.8	35.4	34.7	35.1
Percent Savings from Base	2010 (Basic DL)	2010 20% WWR	Adv. Double Pane	Adv. Triple Pane 2	Quad Solar
(Base used) —>		2010 (w/DL)	2010 (w/DL)	2010 (w/DL)	2010 (w/DL)
1(A) Miami		3.1%	3.2%	-1.5%	3.4%
2(A) Houston		3.3%	4.3%	1.2%	4.7%
4(A) Baltimore		2.4%	3.9%	4.4%	4.4%
6(A) Burlington		3.4%	7.1%	9.2%	8.2%
2(B) Phoenix		4.1%	5.2%	0.8%	5.6%
4(B) Albuquerque		2.5%	2.1%	1.3%	3.4%
6(B) Helena		3.0%	6.7%	8.6%	7.6%

Copy of Table B-3 Selected High Performance Windows, from a baseline of 90.1-2004 and 90.1-2010

	Base(2004 & 2010)	Advanced Double Pane (High VT)	Advanced Triple Pane #1 (High VT, Low U)	Advanced Triple Pane #2 (High VT & SHGC, Low U)	Quad Pane	EC off (approx.)	EC on (approx.)
CZ 1,2,3							
U Value	0.56	0.36	0.18	0.14	0.10	0.30	0.30
SHGC	0.25	0.25	0.39	0.47	0.29	0.48	0.14
Tvis	0.35	0.57	0.6	0.61	0.45	0.65	0.10
CZ 4,5,6							
U Value	0.47	0.35	0.18	0.14	0.10	0.30	0.30
SHGC	0.39	0.35	0.39	0.47	0.29	0.48	0.14
Tvis	0.60	0.62	0.60	0.61	0.45	0.65	0.10

Note: Window prescriptive requirement specifications are currently the same for 90.1-2004 and 90.1-2010.

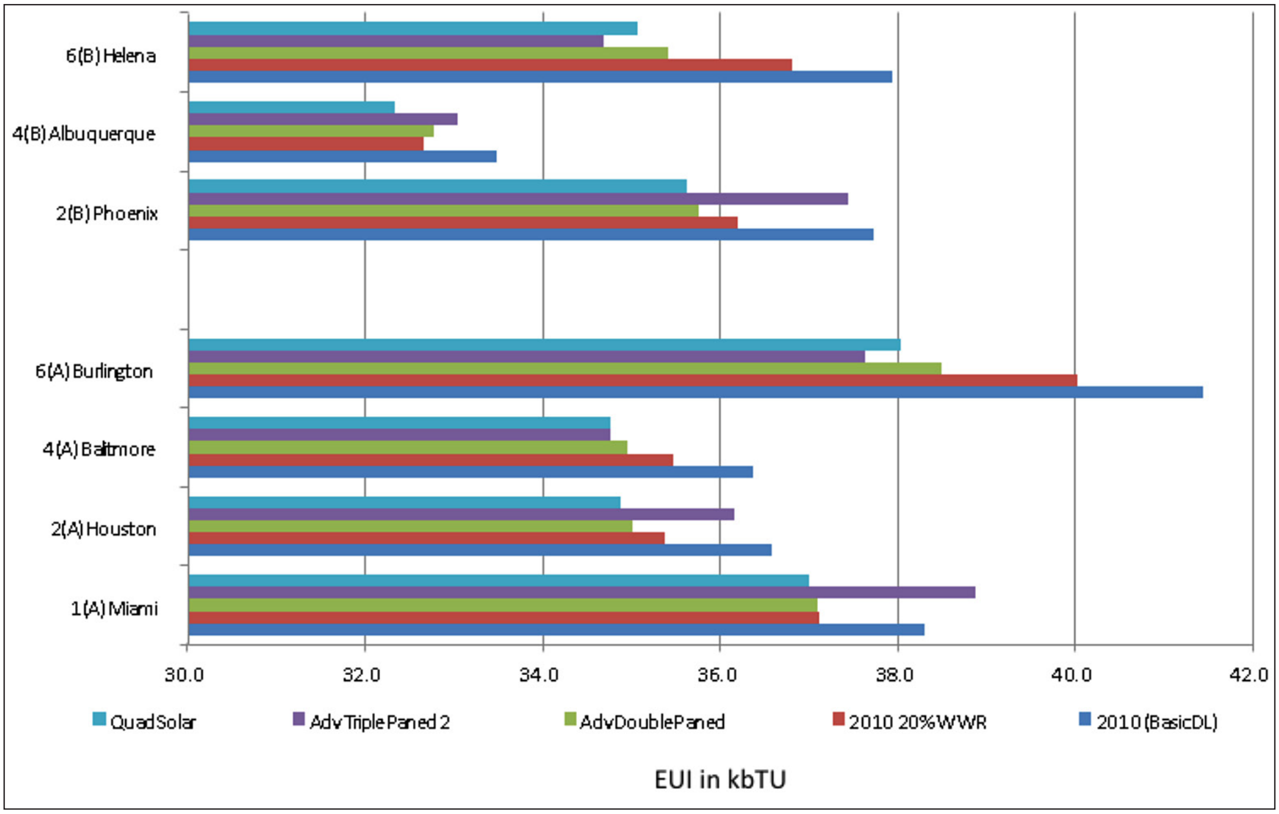

Figure B-25: Bar graph of Site EUI Performances for selected advanced window types (Baseline is 90.1-2010 with prescriptive DL requirements, Site Energy)

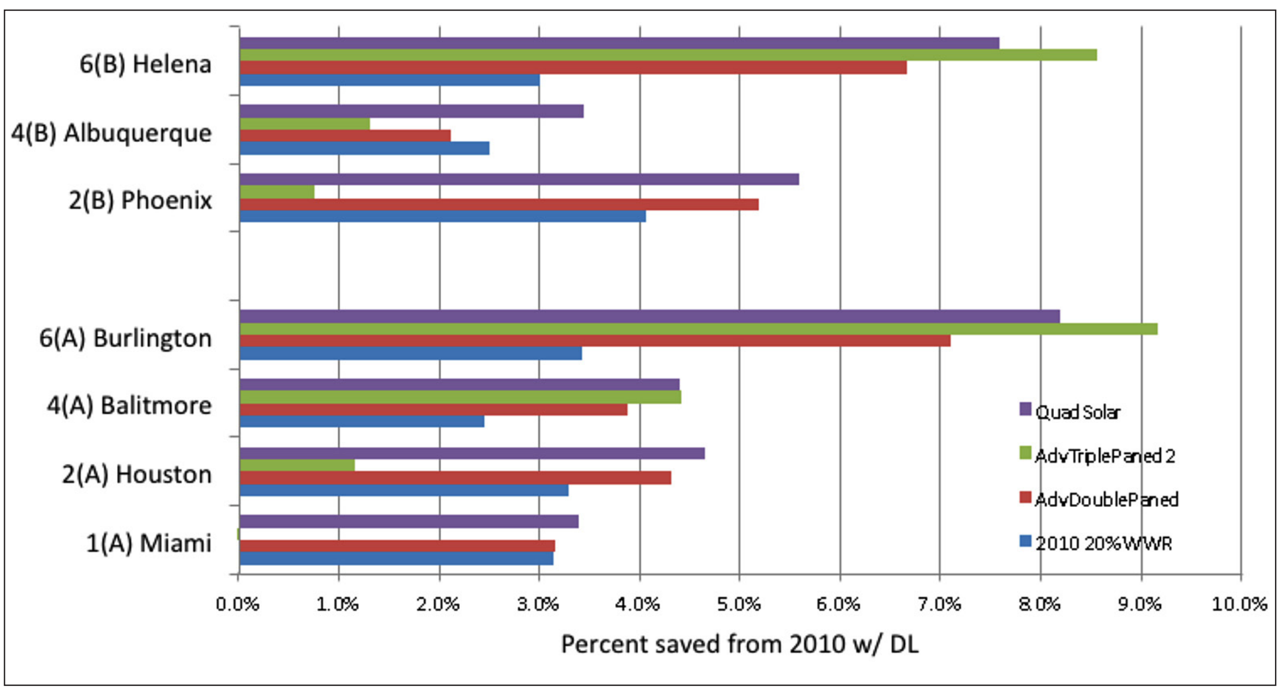

Figure B-26: Bar graph of Site Percent Savings for selected individual advanced window types (Baseline is 90.1-2010 with prescriptive DL requirements, Site Energy)

Several advanced window types were tested with various combinations of U-value, SHGC, and Tvis. Table B-3 lists the values of these variables for the windows presented in the chart and graphs.

Glare control: Manually controlled glare control devices (i.e., blinds, shades, etc.) have been modeled in consistent fashion with the modeling performed in the 90.1-2004 and 90.1-2010 reference building models. In the 90.1-2004 Appendix G modeling rules, modeling of manually controlled shading devices was explicitly not allowed, either for the proposed design or for the baseline building. See 90.1-2004 Appendix G, Table 3.1, Building Enclosure. A significant change (and advancement in reasonableness) occurred. In the 90.1-2010 Appendix G modeling rules, modeling of manually controlled shading devices may either be modeled or not modeled, so long as modeling is consistent for both the proposed design and for the baseline building. See 90.1-2010, Appendix G, Table 3.1, Building Enclosure.

The simulations in this study have used consistent approaches for manually operated shading devices as have been used in the PNNL reference buildings. There is not a guarantee that excess glare is excluded or that visual comfort conditions are provided by the 90.1 -2004 baseline simulations. The 90.1-2010 simulations from PNNL may include manually controlled devices, but we suspect not. We will check on this. Thus, glare control has not been an explicit aspect of these simulations. In a real office building, occupants may deploy blinds or take other measures that would adversely impact the daylighting in the office space. Such measures by occupants would be taken for all simulations. The simulations of combined measures described in the last section of this appendix, and in the fenestration report, do include external shading devices which helped to reduce, but not necessarily eliminate, excess glare conditions. We recommend further analysis of glare issues in future phases of this work.

Electrochromic windows: For electrochromic windows, two different types of controllers were used for simulations, one based on a glare index, the other based on daylight levels. However these were deemed to be of dubious accuracy and we have not had the opportunity in this phase to explore more sophisticated control possibilities for the electrochromic windows. When time permits we would like to explore more sophisticated control options for the electrochromic windows, and for other dynamic shading devices, using the capabilities of the Building Control Virtual Test Bed (BCVTB) being developed at LBNL. The simulation team recommends that the results for the electrochromic simulations not be used as a indicator of daylighting results. The simulation team would like to re-simulate the controls for the electrochromic windows using a more robust control algorithm before drawing conclusions.

> *"The Building Controls Virtual Test Bed (BCVTB) is a software environment that allows expert users to couple different simulation programs for co-simulation, and to couple simulation programs with actual hardware. For example, the BCVTB allows simulation of a building in EnergyPlus and the HVAC and control system in Modelica, while exchanging data between the software as they simulate. The BCVTB is based on the Ptolemy II software environment."*[7]

Triple Glazed Window and SHGC: The triple glazed window presented in this section was chosen specifically for the cooler, heating dominated northern climate zones. This window has a high SHGC (0.47), which is of benefit in the colder climates, but is a significant liability in the warmer climates.

Table B-22: Source Energy (EUI) Performances for Individual Advanced Window Measures (Baseline is 90.1-2010 with prescriptive DL requirements, Source Energy)

Energy Per Total Building Area [kBTU/ft^2]	2010 (Basic DL)	2010 20% WWR	Adv. Double Pane	Adv. Triple Pane 2	Quad Solar
1(A) Miami	116.8	113.0	112.9	118.6	112.6
2(A) Houston	109.9	106.0	104.5	108.5	104.1
4(A) Baltimore	101.8	97.9	97.4	97.5	95.5
6(A) Burlington	107.9	102.6	99.7	98.3	97.1
2(B) Phoenix	114.3	109.4	107.9	113.4	107.5
4(B) Albuquerque	96.5	93.0	94.2	95.6	92.1
6(B) Helena	101.2	96.4	94.0	93.1	91.8
Percent Savings from Base (Base used) —>	2010 (Basic DL)	2010 20% WWR 2010 (w/DL)	Adv. Double Pane 2010 (w/DL)	Adv. Triple Pane 2 2010 (w/DL)	Quad Solar 2010 (w/DL)
1(A) Miami		3.3%	3.3%	-1.5%	3.5%
2(A) Houston		3.6%	4.9%	1.3%	5.3%
4(A) Baltimore		3.8%	4.3%	4.2%	6.1%
6(A) Burlington		5.0%	7.6%	8.9%	10.0%
2(B) Phoenix		4.3%	5.5%	0.8%	5.9%
4(B) Albuquerque		3.6%	2.3%	1.0%	4.5%
6(B) Helena		4.7%	7.0%	8.0%	9.2%

7 https://gaia.lbl.gov/bcvtb

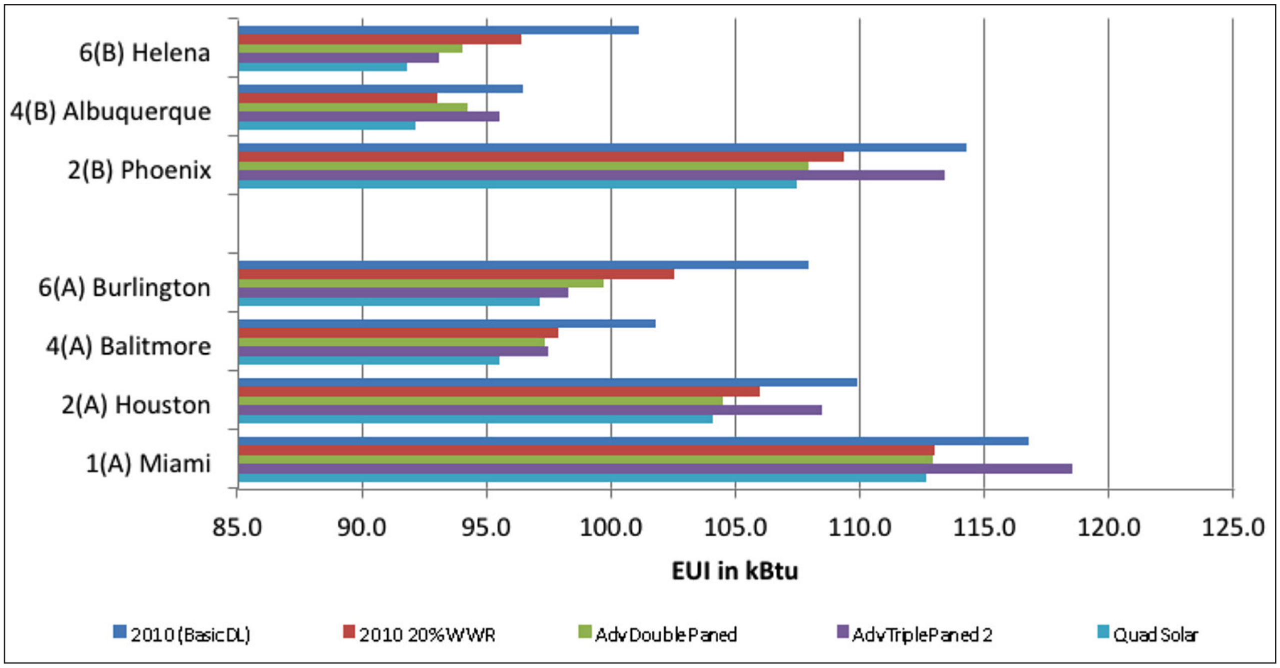

Figure B-27: Bar graph of Source EUI Performances for selected advanced window types (Baseline is 90.1-2010 with prescriptive DL requirements, Source Energy)

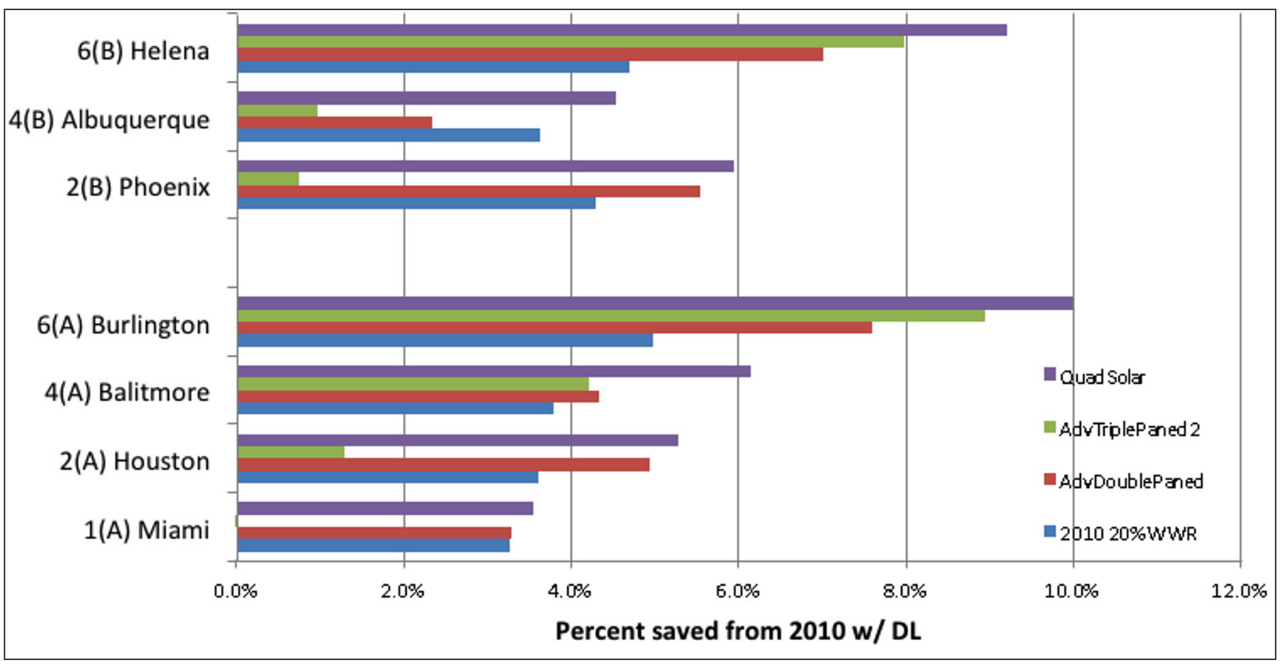

Figure B-28: Bar graph of Source Percent Savings for selected individual advanced window types (Baseline is 90.1-2010 with prescriptive DL requirements, Source Energy)

B-7 Simulation Results for WWR Variations

The simulation results indicate that increasing window to wall ratio (WWR) carries a substantial energy penalty.

For window to wall ratio, there is essentially a linear increase in building energy use as WWR increases. The amount of change varies by climate location. The percentage increase in whole building energy performance from WWR=0.20 to WWR = 0.60, using our modified 2004 vintage reference buildings with 2010 vintage HVAC and lighting, is about:

- 10% to 11% increase in Miami, Houston, or Phoenix (Climate Zones 1 & 2)
- 13% to 14% increase in Baltimore or Albuquerque (Climate Zone 4)
- 16% increase in Burlington or Helena (Climate Zone 6)

A WWR=0.20 (purple on the graphs) shows substantial changes from the base case (Dark Blue). Reducing from WWR=0.40 to WWR=0.20 has whole building energy impacts roughly equivalent to changing building enclosure prescriptive requirements from those in 90.1-2004 to those in 90.1-2010 (including both daylighting and continuous air barrier requirements). This holds true for both cooling dominated southern climate zones and heating dominated northern climate zones.

One implication of these results is that designers should be careful about increasing WWR when using daylighting, for the increased WWR is likely to partially or completely offset the energy or cost savings from daylighting. If WWR is increased substantially over a non-daylighting base case, the resultant design with high WWR and daylighting might use more energy than the base case.

However, advanced daylighting solutions are achievable with little or no increase in WWR. See for example the advanced daylighting solution described below in Section A-7.

Table B-23: Individual Site Energy (EUI) Performance of Different Window to Wall Ratios for ASHRAE 90.1-2004 (BP) Design and Improved ASHRAE 90.1-2010 (P+) (Baseline is 90.1-2004 40 WWR no DL, Site Energy)

Energy Per Total Building Area [kBTU/ft^2]	2004 40 WWR (No DL)	2004 60 WWR (No DL)	2004 33 WWR (No DL)	2004 20 WWR (No DL)	2010 40 WWR (w/DL)
1(A) Miami	41.2	43.0	40.5	39.3	39.0
2(A) Houston	39.5	41.5	38.8	37.5	37.3
4(A) Baltimore	40.7	43.0	39.9	38.7	37.2
6(A) Burlington	46.6	50.1	45.2	43.2	42.6
2(B) Phoenix	40.9	43.3	40.1	38.4	38.6
4(B) Albuquerque	37.0	39.0	36.3	35.3	34.1
6(B) Helena	42.1	45.2	41.0	39.4	38.9
Percent Savings from Base	**2004 40 WWR (No DL)**	**2004 60 WWR (No DL)**	**2004 33 WWR (No DL)**	**2004 20 WWR (No DL)**	**40 WWR**
(Base used) —>		2004 40 WWR (No DL)	2004 40 WWR (No DL)	2004 40 WWR (No DL)	2004 40 WWR (No DL)
1(A) Miami		-4.4%	1.6%	4.7%	5.4%
2(A) Houston		-5.0%	1.8%	5.1%	5.7%
4(A) Baltimore		-5.7%	1.8%	4.8%	8.6%
6(A) Burlington		-7.6%	3.0%	7.2%	8.5%
2(B) Phoenix		-5.8%	2.1%	6.1%	5.7%
4(B) Albuquerque		-5.3%	1.8%	4.6%	7.7%
6(B) Helena		-7.4%	2.6%	6.3%	7.5%

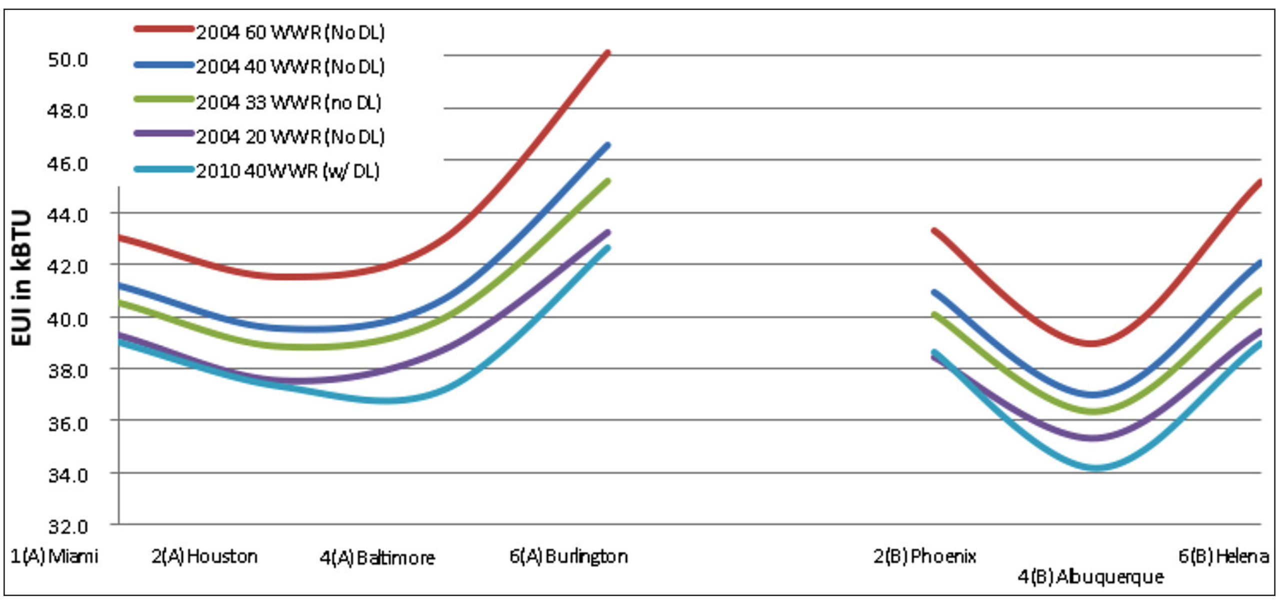

Figure B-29: Line graph of different window to wall ratios for Site EUI for 90.1-2004 (no daylighting)

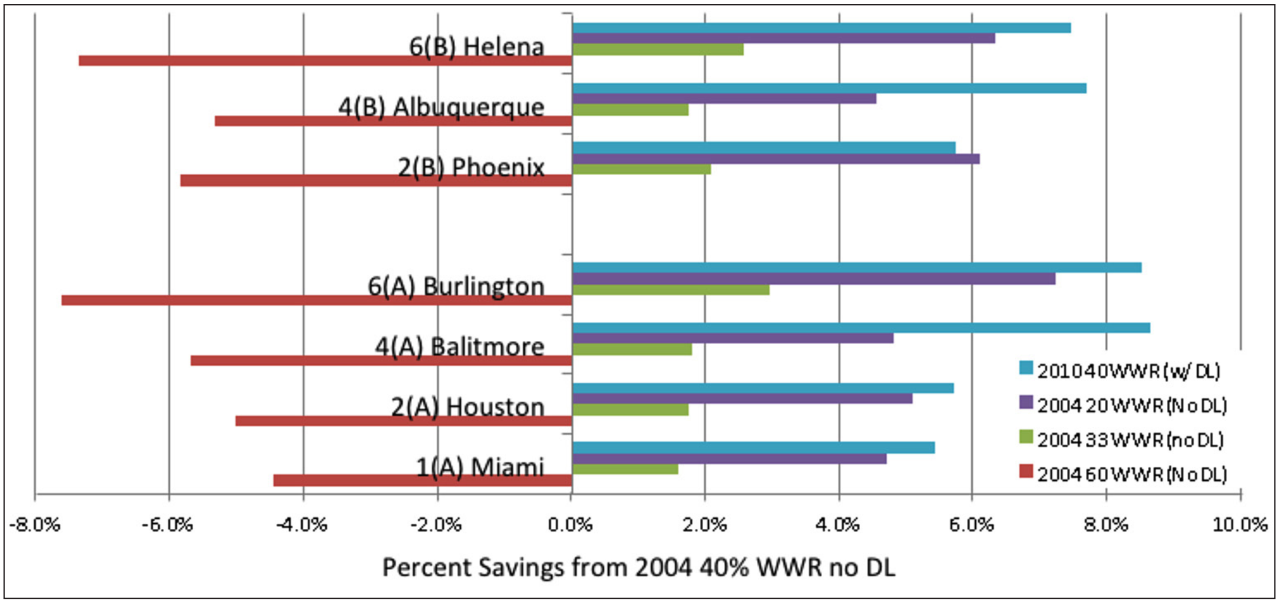

Figure B-30: Bar graph of Site Percent Savings for different window-to-wall ratios from 90.1-2004 (no daylighting)

Table B-24: Individual Source Energy (EUI) Performance of Different Window to Wall Ratios for ASHRAE 90.1-2004 (BP) Design and Improved ASHRAE 90.1-2010 (P+) (Baseline is 90.1-2004 40 WWR no DL, Site Energy)

Energy Per Total Building Area [kBTU/ft^2]	2004 40 WWR (No DL)	2004 60 WWR (No DL)	2004 33 WWR (No DL)	2004 20 WWR (No DL)	2010 40 WWR (w/DL)
1(A) Miami	126.0	131.8	123.9	119.8	118.8
2(A) Houston	119.3	125.5	117.1	112.8	112.1
4(A) Baltimore	114.7	121.7	112.4	108.2	104.3
6(A) Burlington	122.6	132.6	118.9	112.8	111.4
2(B) Phoenix	124.4	132.0	121.7	116.4	116.9
4(B) Albuquerque	107.3	113.6	105.2	101.5	98.7
6(B) Helena	113.5	122.7	110.3	105.1	104.2
Percent Savings from Base (Base used) —>	2004 40 WWR (No DL)	2004 60 WWR (No DL) 2004 40 WWR (No DL)	2004 33 WWR (No DL) 2004 40 WWR (No DL)	2004 20 WWR (No DL) 2004 40 WWR (No DL)	40 WWR 2004 40 WWR (No DL)
1(A) Miami		-4.6%	1.7%	4.9%	5.6%
2(A) Houston		-5.3%	1.9%	5.4%	6.0%
4(A) Baltimore		-6.1%	2.0%	5.6%	9.1%
6(A) Burlington		-8.2%	3.0%	8.0%	9.1%
2(B) Phoenix		-6.1%	2.2%	6.4%	6.0%
4(B) Albuquerque		-5.8%	2.0%	5.4%	8.0%
6(B) Helena		-8.1%	2.8%	7.4%	8.2%

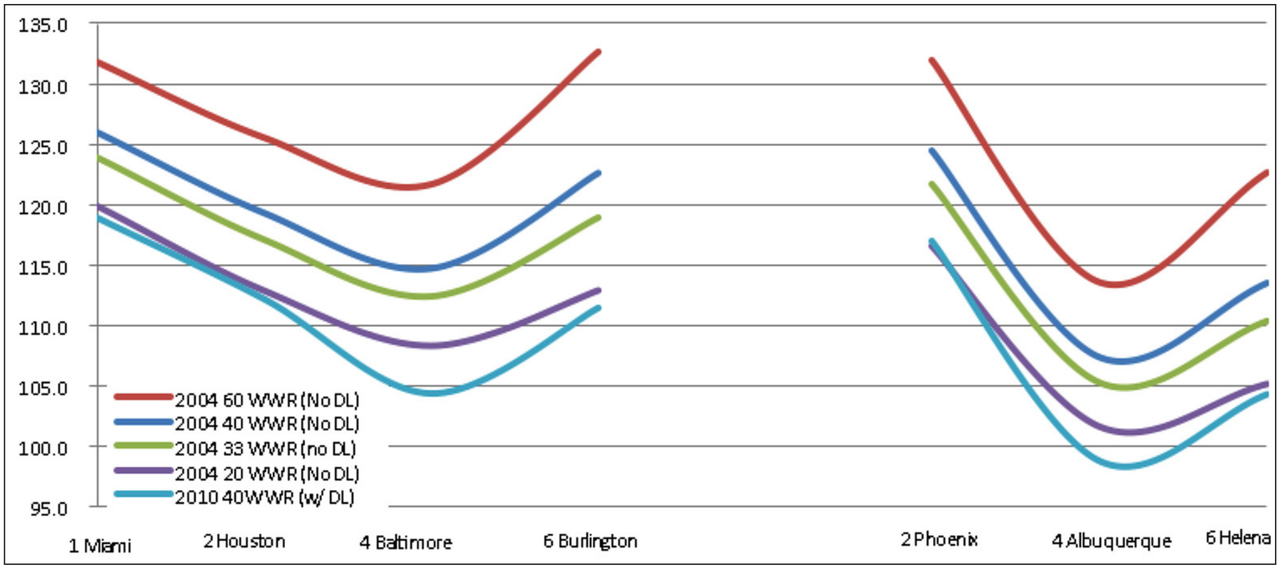

Figure B-31: Line graph of different window to wall ratios for Source EUI for 90.1-2004 (no daylighting)

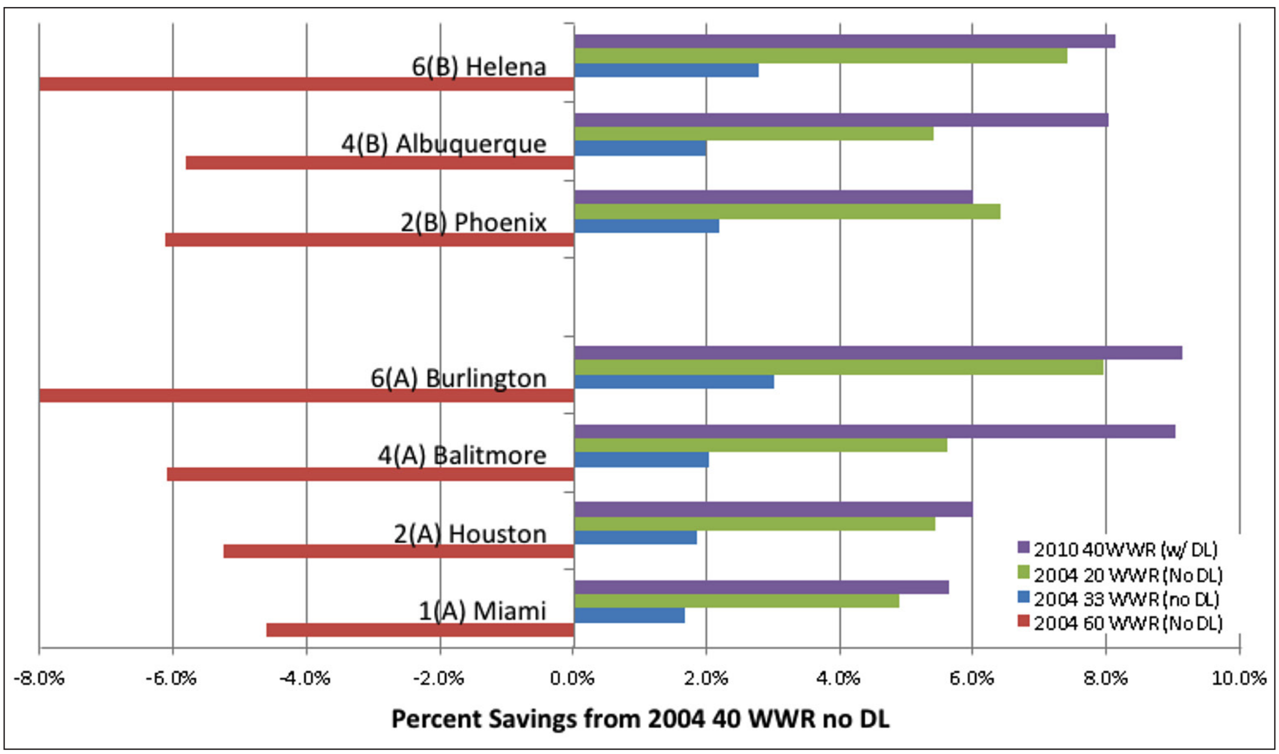

Figure B-32: Bar graph of Source Percent Savings for different window-to-wall ratios from 90.1-2004 (no daylighting)

B-8 Simulation Results for Advanced Daylighting

Advanced daylighting, as simulated for this analysis, involves a few key elements:

- Increase the percent of the floor plate with daylighting controls from ~60% to 100%. This includes:
  - Increase building aspect ratio from the original 1.5:1 to 3:1 in order to increase percent of building floor area that can effectively use daylighting.
  - Increase perimeter zone ceiling heights and window head heights from the original 9 feet to 11 feet, also to increase percent of building floor area that can effectively use daylighting.
- Use continuous dimming controls, which maintain illumination levels at or above a 50 footcandle level for task illumination in the building zones with daylighting controls. Two control locations are employed in each zone, at progressive distances in from the windows.

Preliminary results are shown below that incorporate the above strategies. Results in this section include various combinations of the above measures.

Table B-25: Individual and Bundled Site Energy (EUI) Performance of ASHRAE 90.1-2004 (BP) Design and Improved ASHRAE 90.1-2010 (HP) Design with 3:1 Aspect Ratio with north-south axis, increased window head height, and use of continuous dimming controls (Baseline is 90.1-2004 no DL, Site Energy)

Energy Per Total Building Area [kBTU/ft^2]	2004 (No DL)	2004 (w/DL)	2010 (w/DL)	2010 (w/ Imp DL)	2010 3:1 (w/DL)	2010 RW++ 3:1 (w/DL)	2010 RW-HP 3:1 (w/DL)
1(A) Miami	40.5	38.6	38.3	37.2	35.8	35.3	35.0
2(A) Houston	38.8	37.1	36.6	35.6	34.5	33.9	33.6
4(A) Baltimore	39.9	38.5	36.4	35.5	36.3	35.9	35.8
6(A) Burlington	45.2	44.1	41.4	40.9	44.5	43.8	43.5
2(B) Phoenix	40.1	38.2	37.7	36.6	35.3	34.4	33.9
4(B) Albuquerque	36.3	34.8	33.5	32.4	32.1	31.7	31.5
6(B) Helena	41.0	39.9	37.9	37.3	39.8	38.9	38.5

Percent Savings from Base (Base used) —>	2004 (No DL)	2004 (w/DL) 2004 (No DL)	2010 (w/DL) 2004 (No DL)	2010 (w/ Imp DL) 2004 (No DL)	2010 3:1 (w/DL) 2004 (No DL)	2010 RW++ 3:1 2004 (No DL)	2010 RW-HP 3:1 (w/DL) 2004 (No DL)
1(A) Miami		4.8%	5.5%	8.3%	11.7%	13.0%	13.8%
2(A) Houston		4.5%	5.8%	8.3%	11.2%	12.7%	13.5%
4(A) Baltimore		3.5%	8.9%	11.2%	9.0%	10.0%	10.3%
6(A) Burlington		2.5%	8.3%	9.5%	1.5%	3.1%	3.8%
2(B) Phoenix		4.5%	5.8%	8.6%	12.0%	14.1%	15.4%
4(B) Albuquerque		4.2%	7.8%	10.8%	11.8%	12.9%	13.4%
6(B) Helena		2.7%	7.4%	8.9%	3.0%	5.1%	6.1%

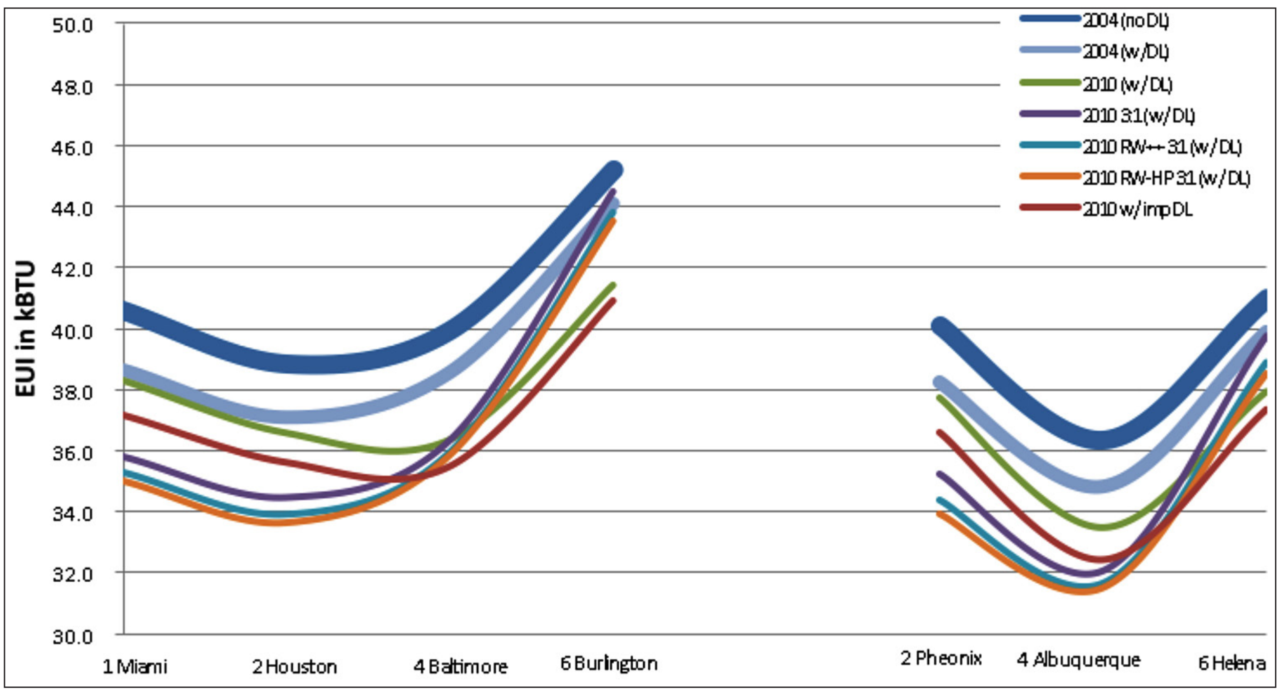

Figure B-33: Line Graph of Site EUI for 3:1 aspect ratio building with increased window head heights and dimming controls.

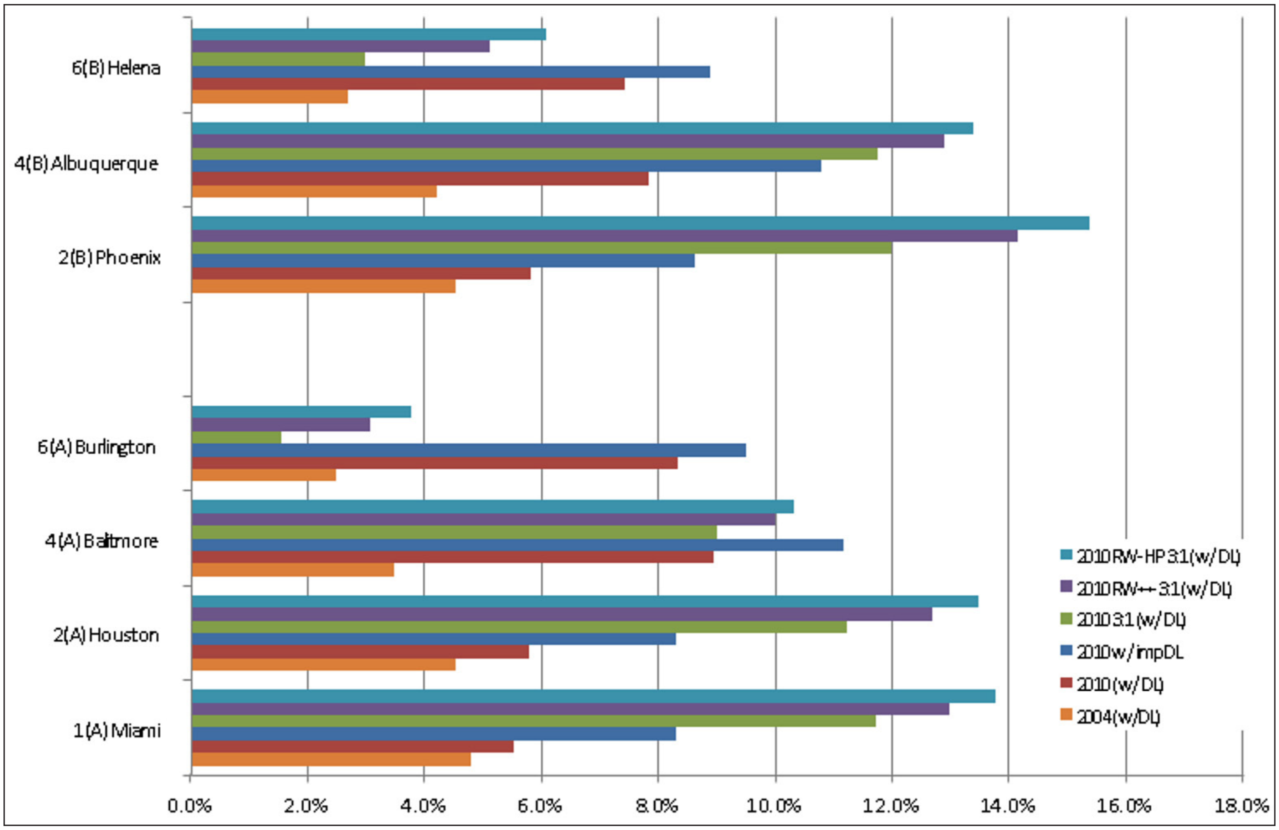

Figure B-34: Bar Graph of Site Percent savings for 3:1 aspect ratio building with increased window head heights and dimming controls.

Changing the aspect ratio to a 3:1 building and increasing the ceiling and window head heights has the effect of shifting more floor area to the perimeter and shrinking the core zone.

1. The bold dark blue line shows the results from the baseline 901-2004 prescriptive requirements without daylighting.
2. The red line show results from changing aspect ratio from 1.5:1 to 3:1 (n-S axis) and increasing window head height from 9 feet to 11 feet, then the building uses slightly more energy due to the larger perimeter zone, as indicated by the red line.
3. The lighter bold blue line shows that adding continuous dimming daylighting controls to the base building (no change in either aspect ratio from 1.5:1 and no change in window head height from 9 feet) results in a moderate reduction in whole-building energy use.
4. Adding continuous dimming daylighting controls to the elongated 3:1 aspect ratio building with increased window head heights,

had a dramatic effect on whole-building energy performance, more than doubling the savings from adding daylighting to the base building in the southern zones. In the north, the savings are more modest.

The increase in the portion of the floorplate with daylighting controls also has a pretty large impact. In the PNNL model, approximately 60% of the floor plate was controlled with stepped controllers. This follows the very conservative daylighting metric found in 90.1-2010, which effectively prescribes only one head height of daylighting into the space. Conventional wisdom dictates that one gets effective daylighting 2-2.5 times the head height of the window, which for this model building, would allow the entire perimeter zone to be daylit.

We also tested the differences between using stepped controllers and continuous controllers. Continuous controllers offered minor savings over stepped controllers, on the order of 0.2 kBtu/sf.

B-9 Simulation Results for Shading Devices

This section reports results for employing external overhangs on all 4 building facades.

B-9.1 Simulation of Fixed External Shading

Standard 90.1 provides credit only for exterior overhangs, and not for vertical fins. Vertical fins were not simulated in this study. External overhangs as shading devices can have a significant impact on energy performance in the southern climate zones, especially when combined with windows with advanced combinations of U-Factors, SHGC, and VT. In the northern zones, the net effect can be negative under some conditions because solar gains through the windows help offset heating costs. However, the beneficial solar heat gain can have negative visual and thermal comfort impacts.

The fixed overhangs shown in this section are of three projection factors, 25%, 50%, and 75%. These PFs may not be optimal for each climate.

Table B-26 shows the percent reductions in whole building energy performance achieved from the addition of three levels of fixed external overhangs, with projection factors of 0.25, 0.50., and 0.75. The base case for each of these cases is the medium office building that meets the ASHRAE 90.1-2010 requirements including the prescriptive daylighting requirements.

Table B-26: Percent Reductions in whole building energy performance criteria for fenestration assembly plus fixed External Shades (Overhangs)

Percent Savings from Base *(Base used) --->*	Fixed Overhang: 25% PF *2010 (basic DL)*	Fixed Overhang: 50% PF *2010 (basic DL)*	Fixed Overhang: 75% PF *2010 (basic DL)*
1(A) Miami	0.6%	1.6%	2.7%
2(A) Houston	0.5%	1.4%	2.1%
4(A) Baltimore	0.0%	-2.3%	-2.3%
6(A) Burlington	0.3%	-2.0%	-5.6%
2(B) Phoenix	1.0%	2.1%	3.1%
4(B) Albuquerque	-0.1%	0.0%	0.5%
6(B) Helena	0.2%	-0.1%	-3.6%

Fixed shades produced percent energy reductions as follows:

0.75 projection factor:

- 2.1 to 3.1 % reductions in climate zones 1 and 2
- Slight to negative reductions elsewhere

0.50 projection factor:

- 1.4 to 2.1 % reductions in climate zones 1 and 2
- Zero to negative reductions elsewhere

0.25 projection factor:

- 0.5 to 1.0 % reductions in climate zones 1 and 2
- Zero to negative reductions elsewhere

Note: in climates zones 1 and 2, fixed overhangs with project factors of 0.50 or 0.75 produce about the same percentage of whole building energy reduction from the 90.1-2010 baseline as does adding advanced insulation to both opaque roof and walls at P++ or HP levels.

B-9.2 Simulation of Dynamic External Shading

From experimental results we have seen, we think that dynamic external shading holds great promise for providing substantial improvements in energy performance of fenestration beyond 90.1-2010. We have conducted preliminary simulations of dynamic shading devices, but have not reported results here, since we are aware of the limitations of the shading control algorithms available within EnergyPlus. We plan to examine more refined control algorithms available via the Building Control Virtual Test Bed (BCVTB) being developed at LBNL (see https://gaia.lbl.gov/bcvtb) that can provide much more refined control of shading by being linked to EnergyPlus at run time.

B-10 Whole building energy simulation results for combinations of measures representing the four energy performance levels: PB, P+, P++, and HP.

Combinations of high performance measures were simulated in EnergyPlus in order to provide an estimate of how much whole building energy conservation savings might be obtained at each of the three advanced levels – P+, P++, and HP – from the baseline level - PB.

The following is a draft set of parametric results from EnergyPlus for selected high performance enclosure measures (i.e., thermal performance levels) across three benchmark energy performance levels: P+,P++, and HP.

Baseline: The estimates below use as a baseline the 90.1-2004 reference building model from PNNL, using TMY3 weather files, and modified for these enclosure analyses to include HVAC and lighting systems that meet 90.1-2010 vintage requirements in order to isolate the impacts of the building enclosure measures.

For the P++ level the combined measures and features are:

CZ 1, 2:

1. Improved Continuous daylighting controls, but window head height not increased and building aspect ratio not changed.
2. Overhang, 50% PF
3. Double pane window #1: U = 0.36, SHGC = 0.25, Tv = 0.57
4. Infiltration = 0.1.
5. Improved opaque enclosure measures to P++ level as discussed above.

CZ 4:

1. Improved Continuous daylighting controls, but window head height not increased and building aspect ratio not changed.
2. Double pane window #2: U= 0.35, SHGC = 0.35, Tv = 0.62
3. Infiltration = 0.1.
4. Improved opaque enclosure measures to P++ level as discussed above.

CZ 6, 7:

1. Improved Continuous daylighting controls, but window head height not increased and building aspect ratio not changed.
2. Overhang, PF = 0.25
3. Double pane window #2: U= 0.35, SHGC = 0.35, Tv = 0.62
4. Infiltration = 0.1
5. Improved opaque enclosure measures to P++ level as discussed above.

For the HP level the combined measures and features are:

CZ 1, 2:

1. Improved Continuous daylighting controls, plus window head height is increased and building aspect ratio is changed from 1.5:1 to 3:1.
2. Overhang, PF = 0.75
3. Quadruple pane window: U= 0.1, SHGC = 0.29, Tv = 0.45
4. Infiltration = 0.1
5. Improved opaque enclosure measures to HP level as discussed above.

CZ 4:

1. Improved Continuous daylighting controls, but window head height not increased and building aspect ratio not changed.
2. Quadruple pane window: U= 0.1, SHGC = 0.29, Tv = 0.45
3. Infiltration = 0.1.
4. Improved opaque enclosure measures to HP level as discussed above.

CZ 6, 7:

1. Improved Continuous daylighting controls, but window head height not increased and building aspect ratio not changed.
2. Triple pane window: U= 0.14, SHGC = 0.47, Tv = 0.61
3. Infiltration = 0.1.
4. Improved opaque enclosure measures to HP level as discussed above.

B-10.1 Percent Energy Conservation Savings, Site Energy

The above combinations of measures produced the site energy results shown in Tables B-27, B-28, and B-29 below and in Figures B - 35.

Table B-27: Whole Building Energy (EUI) Performance Levels for PB, P+, P++, and HP for Packages of Enclosure measures (Baseline is PNNL 90.1-2004 Reference Building using TMY3 weather data)

Energy Per Total Building Area [kBTU/GSF/yr]	2004 PNNL TMY3 Base	2010 Ltg& HVAC 2004 Env Base (PB)	90.1-2010 (Basic DL) P+	Final P++	Final HP
1(A) Miami	50.5	40.5	38.3	34.7	33.0
2(A) Houston	51.1	38.8	36.6	33.3	31.8
4(A) Baltimore	51.8	39.9	36.4	33.8	33.9
6(A) Burlington	58.5	45.2	41.4	37.2	36.1
2(B) Phoenix	50.7	40.1	37.7	33.6	32.0
4(B) Albuquerque	46.1	36.3	33.5	31.4	31.2
6(B) Helena	53.9	41.0	37.9	34.1	33.0

Table B-28: Percent of whole building site energy reduction for P+, P++, and HP Performance Levels for Packages of Enclosure measures(Baseline used is PNNL 90.1-2004 Reference Building using TMY3 weather data)

Percent Savings from Base (Base used) —>	2004 (Basic DL) 2004 PNNL TMY3 Base	Final P++ 2004 PNNL TMY3 Base	Final HP 2004 PNNL TMY3 Base
1(A) Miami	24.1%	31.2%	34.7%
2(A) Houston	28.4%	34.8%	37.8%
4(A) Baltimore	29.8%	34.8%	34.5%
6(A) Burlington	29.2%	36.3%	38.2%
2(B) Phoenix	25.6%	33.7%	36.9%
4(B) Albuquerque	27.4%	31.9%	32.3%
6(B) Helena	29.6%	36.8%	38.7%

Table B-29: Percent of whole building site energy reduction for P+, P++, and HP Performance Levels for Packages of Enclosure measures (Baseline is Modified PNNL 90.1-2004 Reference Building with 2004 Enclosure features and 90.1-2010 Lighting & HVAC features)

Percent Savings from Base (Base used) —>	2010 (Basic DL) 2010 Ltg & HVAC 2004EnvBase	Final P++ 2010 Ltg & HVAC 2004EnvBase	Final HP 2010 Ltg & HVAC 2004EnvBase
1(A) Miami	5.5%	14.3%	18.7%
2(A) Houston	5.8%	14.2%	18.1%
4(A) Baltimore	8.9%	15.4%	15.1%
6(A) Burlington	8.3%	17.6%	20.1%
2(B) Phoenix	5.8%	16.1%	20.2%
4(B) Albuquerque	7.8%	13.5%	14.0%
6(B) Helena	7.4%	16.8%	19.4%

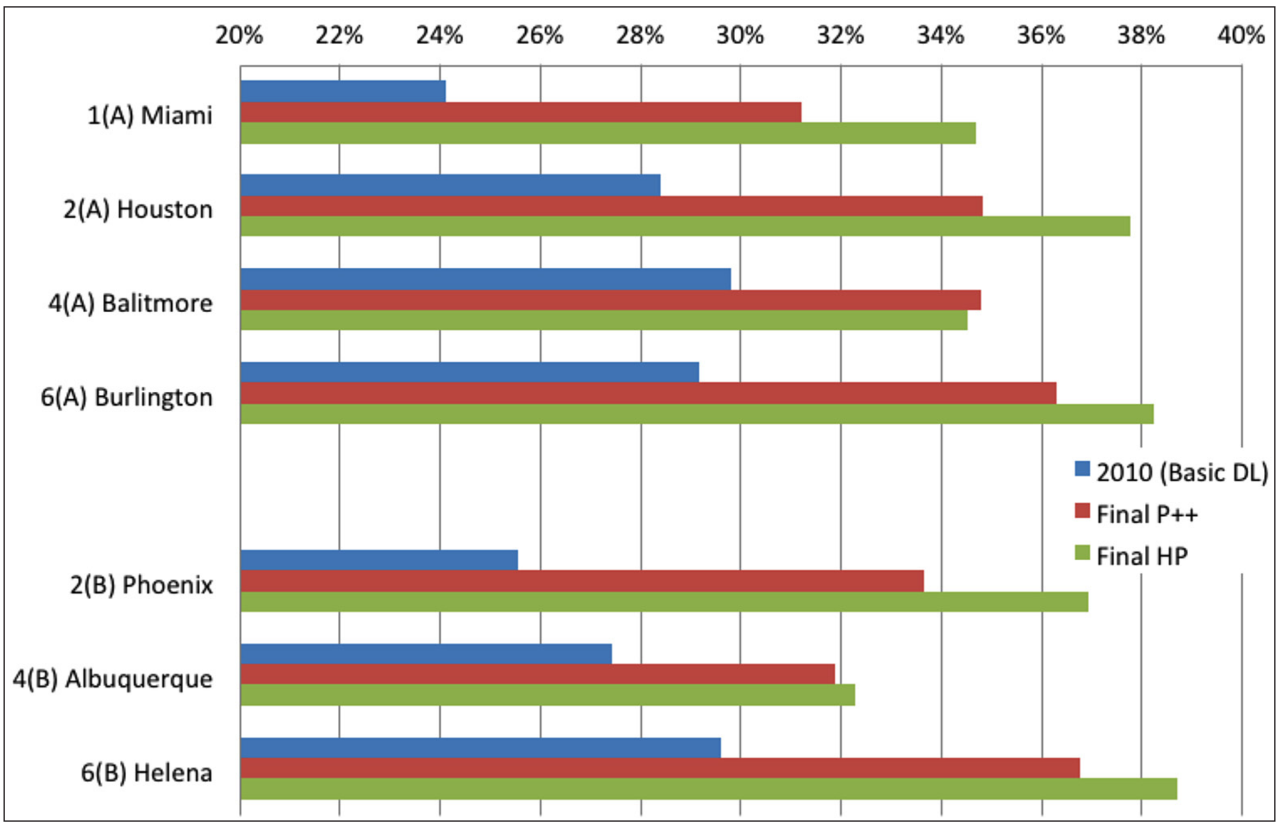

Figure B-35: Whole-Building Results of Combined Measures for P+, P++, & HP, Site Energy PNNL 2004 Base

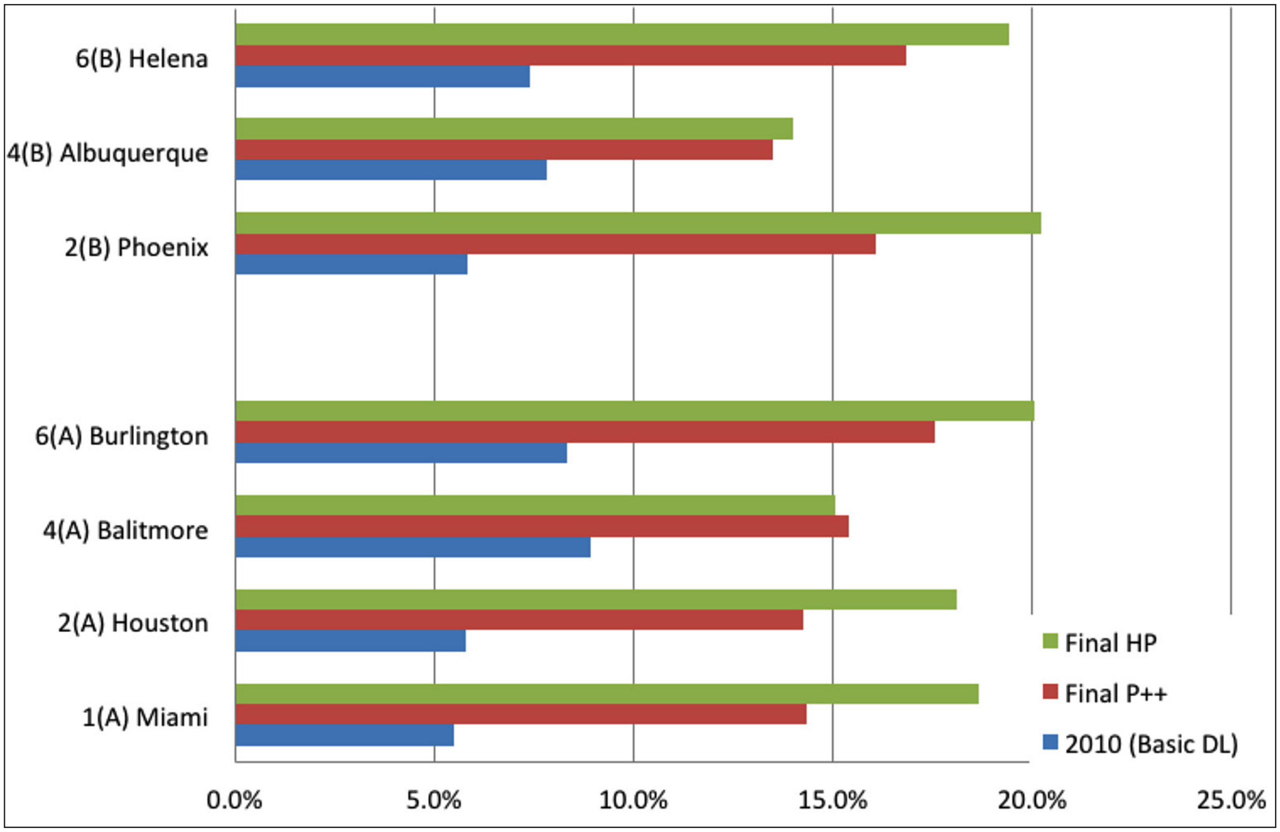

Figure B-36: Whole-Building Results of Combined Measures for P+, P++, & HP, Site Energy Superb 2004 Base

Compared to the PB baseline of 90.1-2004 (no daylighting), the percentage reduction in whole building site energy consumption is in the following ranges:

- The P+ (90.1-2010) level results in percent reductions of 5.5% to 16.0%.
- The P++ (Enhanced) level, results in percent reductions of 13.5% to 21.8%.
- The HP (High Performance) level, results in percent reductions of 14.0% to 25.8%.

The greatest percent reduction by far occurred in northern heating-dominated climate zone 7 (Duluth).

B-10.2 Percent Energy Conservation Savings, Source Energy

The above combinations of measures produced the source energy results shown in the table below and in Figure B-37.

Table B-30: Whole Building Source Energy (EUI) Performance Levels for PB, P+, P++, and HP for Packages of Enclosure measures (Baseline is PNNL 90.1-2004 Reference Building using TMY3 weather data)

Energy Per Total Building Area [kBTU/GSF/yr]	2004 PNNL TMY3 Base	2010 Ltg& HVAC 2004 Env Base (PB)	90.1-2010 (Basic DL) P+	Final P++	Final HP
1(A) Miami	155.3	123.9	116.8	105.4	99.8
2(A) Houston	153.9	117.1	109.9	98.2	93.0
4(A) Baltimore	148.6	112.4	101.8	92.7	91.6
6(A) Burlington	157.3	118.9	107.9	94.3	92.2
2(B) Phoenix	155.3	121.7	114.3	100.3	94.2
4(B) Albuquerque	136.0	105.2	96.5	89.7	88.2
6(B) Helena	148.1	110.3	101.2	88.9	87.8

Table B-31: Percent of whole building site energy reduction for P+, P++, and HP Performance Levels for Packages of Enclosure measures (Baseline used is PNNL 90.1-2004 Reference Building using TMY3 weather data)

Percent Savings from Base (Base used) —>	2004 (Basic DL) 2004 PNNL TMY3 Base	Final P++ 2004 PNNL TMY3 Base	Final HP 2004 PNNL TMY3 Base
1(A) Miami	24.8%	32.1%	35.7%
2(A) Houston	28.6%	36.2%	39.6%
4(A) Baltimore	31.5%	37.6%	38.4%
6(A) Burlington	31.4%	40.1%	41.4%
2(B) Phoenix	25.6%	33.7%	36.9%
4(B) Albuquerque	27.4%	31.9%	32.3%
6(B) Helena	29.6%	36.8%	38.7%

Table B-32: Percent of whole building source energy reduction for P+, P++, and HP Performance Levels for Packages of Enclosure measures (Baseline is Modified PNNL 90.1-2004 Reference Building with 2004 Enclosure features and 90.1-2010 Lighting & HVAC features)

Percent Savings from Base (Base used) —>	2010 (Basic DL) 2010 Ltg & HVAC 2004EnvBase	Final P++ 2010 Ltg & HVAC 2004EnvBase	Final HP 2010 Ltg & HVAC 2004EnvBase
1(A) Miami	5.5%	14.3%	18.7%
2(A) Houston	5.8%	14.2%	18.1%
4(A) Baltimore	8.9%	15.4%	15.1%
6(A) Burlington	8.3%	17.6%	20.1%
2(B) Phoenix	5.8%	16.1%	20.2%
4(B) Albuquerque	7.8%	13.5%	14.0%
6(B) Helena	7.4%	16.8%	19.4%

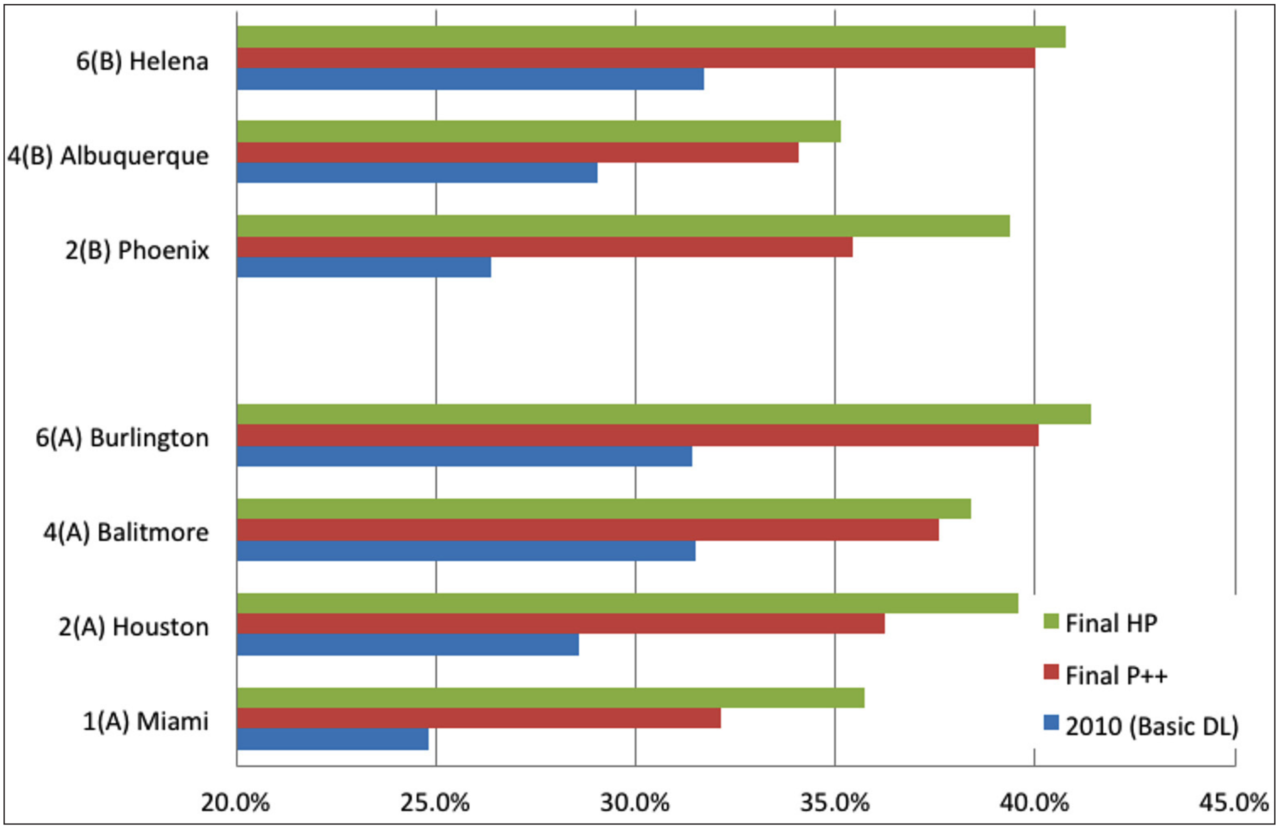

Figure B-37: Whole-Building Results of Combined Measures for P+, P++, & HP, Source Energy PNNL 2004 Base

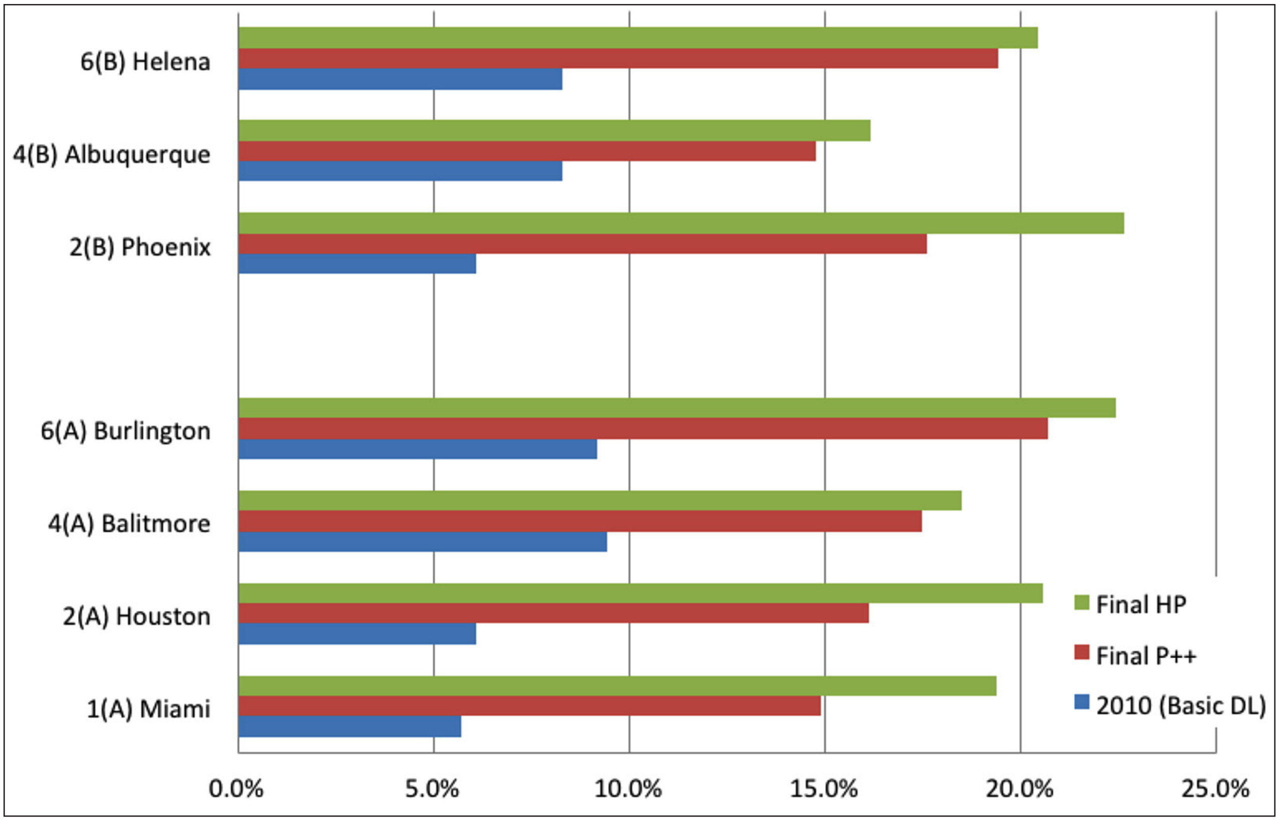

Figure B-38: Whole-Building Results of Combined Measures for P+, P++, & HP, Source Energy Superb 2004 Base

Compared to the PB baseline of 90.1-2004 (no daylighting), the percentage reduction in whole building source energy consumption is in the following ranges:

- The P+ (90.1-2010) level results in percent reductions of 5.7% to 17.2%.
- The P++ (Enhanced) level, results in percent reductions of 14.9% to 25.5%.
- The HP (High Performance) level, results in percent reductions of 16.1% to 28.5%.

The greatest percent reduction by far occurred in northern heating-dominated climate zone 7 (Duluth). For source energy, large energy reductions occurred in cooling dominated climate zones 1 & 2, compared with reductions considering site energy.

C

Detailed Mechanical Technical Analysis

James E. Woods, PhD, PE and Kenneth Schram, PE

In this chapter:

The HVAC/Mechanical analysis summarized in Chapter 5 are discussed in detail in Appendix C.

Appendix C: Detailed Mechanical Technical Analysis Table of Contents

Tables

Introduction

The Energy Independence and Security Act of 2007 (EISA-2007)[1] defines a high-performance building (HPB) as one that "integrates and optimizes on a life-cycle basis all major high-performance attributes, including energy conservation, environment, safety, security, durability, accessibility, cost-benefit, productivity, sustainability, functionality, and operational considerations." EISA-2007 also established an aggressive plan for achieving energy independence (e.g., zero-net-energy) in the nation's building stock by the year 2030.

> The Energy Independence and Security Act of 2007 defines a high-performance building as one that "integrates and optimizes on a life-cycle basis all major high-performance attributes, including energy conservation, environment, safety, security, durability, accessibility, cost-benefit, productivity, sustainability, functionality, and operational considerations.

The U.S. Department of Homeland Security (DHS), Science and Technology Directorate's Infrastructure and Geophysical Division (IGD) has entered into a contract with the National Institute of Building Sciences (NIBS) to extend the HPB concept in an effort to guarantee that blast resistance and chemical, biological and radiological (CBR) protection are included as two key elements of the HPB Security Attribute.

Addressing the challenge that the building enclosure, often the first line of protection against external CBR releases, can also be the most vulnerable element of a building and a significant influence on building energy utilization, the initial phase (i.e., Phase 1) of the project aims to establish benchmarks for enclosure systems that are beyond the minimum levels often expressed in codes to guide building owners and designers weighing tradeoffs among the HPB attributes. The outcome of Phase 1 is expected to provide guidance to the building owner in planning a set of Owner Performance Requirements (OPR) that will optimize the performance of the building enclosure and its interface with the heating, ventilating, and air conditioning (HVAC) system for safety, security, energy, and sustainability performance.

> Addressing the challenge that the building enclosure, often the first line of protection against external CBR releases, can also be the most vulnerable element of a building.

As noted in the Project Report, the technical work of Phase 1 has been organized within four Technical areas: Architectural, Structural, Fenestration, and Mechanical. This report addresses the Phase 1 objectives and scope for Mechanical.

The Mechanical analysis covered objectives (i.e., sub-attributes) to be evaluated within four attributes identified in EISA-2007, as follows:

1. **Security.** Interactive performance of two HPB enclosure sub-attributes: thermal transfer and CBR protection and three HPB HVAC sub-attributes: **pressurization control; filtration control; and sensing, monitoring,** and **control.**
2. **Energy.** Resultant thermal loads from heat transfer through opaque and glazed enclosure areas, and resultant percentages of estimated whole-building energy utilization rates attributable to building enclosures, with and without blast resistance and CBR protection.
3. **Environment.** Resultant percentages of environmental footprints corresponding to the estimated energy utilization rates attributable to building enclosures.
4. **Sustainability.** Opportunities for renewable site energy production to reduce depletion of non-renewable energy resources and to reduce concomitant carbon footprints attributable to building enclosures.

The scope of this work included:

- Identification of useful measurements for sub-attribute performance (Metric).
- Consensus of sub-attribute's high performance levels (Benchmark).
- Selection of methods for verifying and validating benchmarks (Standard).
- Review and respond to industry review of high performance model (Metric + Benchmark + Validation).
- Provide input to requirements and review output of tool for owner that establishes high performance requirements model (Software).

The Mechanical analysis scope for Phase 1 was limited to analysis of: 1) external releases of CBR agents; 2) transport of these agents across the building enclosure; and 3) three HVAC interactions with the enclosure: the effectiveness of filtering the make-up air intake sub-systems; air pressurization control for building enclosures; and sensing, monitoring and control functions related to the building enclosure.

High Performance Criteria

Criteria have been identified and developed, as shown in Appendix C.1, with which to evaluate the sub-attribute of CBR protection from external releases, its impacts on the sub-attributes of energy utilization and environmental footprint attributable to the building enclosure, and the opportunity to offset these impacts with renewable resources.

Attributes

Column A identifies the four EISA-2007 attributes that have been addressed by the Mechanical analysis: Security, Energy, Environment, and Sustainability. [1]

Sub-attributes

Column B identifies sub-attributes for each attribute:

- **Security:**
  - CBR Protection from external releases of Manmade Hazards.
- **Energy:**
  - Thermal Loads resulting from sensible and latent heat transfer through the building enclosure.
  - Whole-Building Energy Utilization rates from which percentages can be attributed to building enclosures.
- **Environment:**
  - Environmental Footprint calculated from the whole-building energy utilization rates and from which percentages can be attributed to building enclosures.
- **Sustainability:**
  - Renewable Energy opportunities for alternative methods of energy production that are associated with building enclosures.

Demands

Columns E – G, of Appendix C.1, identify and explain expressions of demand or threat used to characterize the sub-attributes, columns R - U describe system vulnerabilities, and columns Z - AA describe related operational and resiliency performance impacts.

- **CBR Protection:**
  - **Release Locations (Column E).** Three locations of agent release and three levels of threat have been defined for the Phase 1 OPR:

- **Remote.** Outside of the property boundaries (off-site), with potential threat levels of Moderate to Low.
- **On-site.** Within the property boundaries, with potential threat levels of Moderate to High.
- **Proximate.** Near the building enclosure, including fenestrations and the make-up intake locations, with potential threat levels of High.
  - **Agents (Column F)**: Manmade hazards that are intentionally released to cause harm. These include chemical, biological, and radiological substances, some that are processed to "industrial" or "weaponized" grades. Descriptions of many of these agents, their physical characteristics, and their pathological effects are available in the literature.[2,3,4]
  - **Exposure (Column G):** Exposure has been defined for the Phase 1 OPR as the product of release strength (i.e., airborne concentration of the agent) and the duration of release at its location.
  - **CBR Vulnerabilities (Columns R-U):** For the Phase 1 OPR, vulnerabilities have been defined as the weaknesses of the enclosure (i.e., infiltration, natural ventilation, moisture migration) and HVAC systems (i.e., location of make-up air intakes, filtration effectiveness, and effectiveness of enclosure pressurization control) to protect against exposure from the external CBR releases. Quantitative values of CBR vulnerability have not been established; qualitative values have been defined as High, Moderate, and Low.
  - **Resiliency and Continuous Operations (Columns Z and AA):**
    - Depending on location, strength and duration of the released agent or agents, and the CBR vulnerability of the facility, the impact on continuity of operations and/or shelter-in-place (SIP) areas during and after an attack could range from minor to severe, in a few zones or throughout the whole facility.
    - History indicates that CBR contamination may require evacuation of the zones or building for extensive periods and that furnishings and equipment may require replacement.[5]
- **Thermal Loads:**
  - **Envelope Sensible and Latent Heat Gain and Loss Rates (Column E):** These are instantaneous heat transfer rates through opaque and glazed assemblies, with and without natural ventilation and solar radiation. These demands are further discussed in the Architectural section of the Technical Analysis chapter..

- **Envelope Thermal Loads (Column F):** Thermal loads are sensible heat gain and loss rates that are modified by time lags due to thermal mass of the enclosure assemblies and furnishings within the building, absorption and dissipation of radiant heat gains at interior surfaces, and latent heat gain and loss rates.[6] Envelope thermal loads are transferred primarily by convection (i.e., air distribution) to heat exchange devices within the HVAC system.

- **Envelope Mass Transfer Rates (Column G):** These are transfer rates of air and water vapor masses, which may be contaminated, through opaque and fenestration surfaces by infiltration, permeation, and natural ventilation. These masses are transferred by convection to filtration and latent heat exchange devices within the HVAC system.

- **Thermal Vulnerabilities (Columns R-U):** For the Phase 1 OPR, thermal vulnerabilities have been defined as the weaknesses of the enclosure system to minimize annual average sensible and latent enclosure loads and mass transfer rates during normal operations. Quantitative values of thermal vulnerability have not been established; qualitative values have been defined as Low and Moderate.

- **Resiliency and Continuous Operations (Columns Z and AA):**

  - Depending on location, strength, and duration of blast or CBR release, and the vulnerability of the facility, the impact on continuity of operations (i.e., thermal control) could range from minor to severe, in a few zones or throughout the whole facility.

  - History indicates that failure of the thermal performance of the enclosure may require evacuation of the affected perimeter zones until the enclosure is repaired.

  - These demands are further described in the Technical Report of the Architectural, Fenestration, and Structural Committees.

- **Whole-Building Energy Utilization:**

  - **Site-Energy Mix, Availability, Reliability, and Redundancy (Column E):** The project location, and the functional and resiliency requirements of the owner, will directly affect the whole-building energy utilization targets to be used in the OPR. The mix, availability and reliability demands are also dependent on regional conditions.[7]

  - **Site-Energy Costs and Demand Charges (Column F):** Economic consideration will also directly affect the whole-building energy utilization targets to be used in the OPR. The energy cost and demand charges for electricity, natural gas, and other fuel sources are dependent on regional conditions and policies of the utility providers.[8,9]

- **Percentage of Whole-Building Energy Utilization Attributable to the Building Envelope (Column G):** The thermal load from the building enclosure may be directly affected by treatments for blast resistance and CBR protection. However, this thermal load only indirectly affects energy utilization, as it is adiabatically mixed with other thermal loads (i.e., lighting and electrical power, occupancy density, ventilation, fan power for filtration and pressurization, and system inefficiencies) and transferred to heat exchangers within the HVAC system where energy from renewable and fossil-fuel (e.g., electricity, natural gas, diesel fuel) resources is utilized to establish thermal balances required to provide the building performance.[10] After the whole-building energy utilization rate is estimated (or measured), the percentage attributed to the building enclosure can be calculated, as shown in Appendix C.3, pages 3 and 4.

- **Energy Vulnerabilities (Columns R-U):** For the Phase 1 OPR, energy vulnerability has been defined as the weaknesses of the building enclosure sub-system to comply with the attributable percentage of whole-building energy target for baseline or benchmark performance during normal operations. Quantitative values of energy vulnerability have not been established; qualitative values have been defined as Low and Moderate.

- **Resiliency and Continuous Operations (Columns Z and AA):** Site energy availability, reliability and redundancy are critically important to continuity of operations and to minimizing the duration of lost operations.

- **Environmental Footprint**

  - **Equivalent CO_2 Emission (CO_2e) (Column G):** For the Phase 1 OPR, the environmental footprint has been defined in terms of CO_2e, which is calculated from the regional mix of non-renewable site energy resources (Column F) and the Energy Utilization Intensity (EUI) (Column E), as shown in Appendix C.3, page 1.[7] The percentage of CO_2e that is attributable to the building enclosure has been calculated by the same method as for the energy utilization, described above, and shown in Appendix C.3, page 4.

  - **Environmental Footprint Vulnerabilities (Columns R-U):** Same as Energy Vulnerabilities.

- **Resiliency and Continuous Operations (Columns Z and AA):** Not applicable.

- **Renewable Energy (Opportunities)**

  - **On-Site Energy Use (Column E):** Selection of the mix of renewable site energy uses (e.g., electricity, water heating, space heating, other) will directly affect the choice of types and capacities of renewable energy devices (i.e., solar photovoltaic panels, solar thermal panels, wind turbines). Only roof-mounted solar photovoltaic panels for production of electricity have been considered in the Phase 1 OPR.
  - **On-Site-Energy Production (Column F):** Selection of "economically viable" (i.e., per EISA 2007[1]) production capacities of on-site renewable energy sub-systems will directly affect the expected reductions in whole-building energy utilization targets through the types of renewable energy devices that can be interfaced with the building enclosure (Column G). The solar availability and reliability demands of renewable energy sources are dependent on regional conditions.[11]
  - **Renewable Energy Vulnerabilities (Columns R-U):** For the Phase 1 OPR, vulnerabilities have been defined as the weaknesses of the renewable energy sub-systems (i.e., solar PV) to comply with the expected off-sets in whole-building energy targets for baseline and benchmark performance. Quantitative values of renewable energy vulnerability have not been established; qualitative values have been defined as Low and Moderate.
  - **Resiliency and Continuous Operations (Columns Z and AA):** On-site energy systems that are interfaced with the building enclosure could have either positive or negative impact on continuity of operations and duration of lost operations, dependent upon the performance (e.g., reliability, durability) of the renewable energy sub-systems during response and recovery times.

Baselines and Benchmarks

Baseline and benchmark criteria for the sub-attributes of CBR Protection, Whole-Building Energy Utilization, Environment Footprint, and Renewable Resource Opportunities have been defined in this Report based on federal law and regulations,[1, 12] and published standards and guidance documents from federal agencies[15-19, 22] and from nationally recognized non-governmental organizations.[13, 14, 19-21, 23] Based on the Minutes from the 6 December 2010 meeting:

- **Baseline criteria** have been defined as measurable parameters and values for performance requirements that are consistent with existing building codes and nominal standards of care.
- **Benchmark criteria** have been defined as measureable parameters and values for performance requirements that provide for increased demands/threats, reduced vulnerabilities, and increased resilience.

CBR Protection

A dearth of exposure criteria and data on vulnerability and consequences exist in the scientific and technical literature with which to quantitatively evaluate risk and CBR Protection. However, qualitative criteria for risk and protection evaluation have been identified from three primary references.[12-14] Compliance with the policies and recommendations in the ISC Standard[12] is mandatory for each Federal Agency and Department, "except where the Director of Central Intelligence determines that compliance would jeopardize sources and methods." For facilities under other jurisdictions, compliance with these risk criteria is voluntary.

Table 1 in Appendix C.2 is a composite of these three sets of qualitative criteria. Both the ISC Standard[12] and the ASHRAE Guideline 29[13] define five levels of risk (LOR). The ISC Standard categorizes these LORs as Facility Security Levels (FSL I – V), uses the same descriptors for levels of protection (LOP) as for LOR (i.e., minimum, low, moderate, high, and very high), but does not describe consequences. The ASHRAE Guideline 29 defines five LORs (i.e., negligible, minor, moderate, serious, and critical) in terms of consequences to occupant health and safety and to system performance. The NRC criteria[14] define four LOPs (i.e., low-level passive protection, LP-1; high-level passive protection LP-2; low-level active protection, LP-3; and high-level active protection, LP-4) in terms of consequences to health and safety.

For the Phase 1 OPR, the baseline and benchmark criteria for CBR protection from external releases have been defined to address three qualitative levels of exposure/threat (i.e., Low, Moderate, High), three qualitative levels of vulnerability (i.e., Low, Moderate, High), and the LORs and LOPs from the three primary references as shown in Table 1, Appendix C.2. These combinations have resulted in four categories of CBR Protection, which define **baseline** and three levels of **benchmark** (i.e., P+, P++, and Future/HP) performance criteria that are consistent with those for other sub-attributes (e.g., energy utilization, external blast, external ballistics, seismic and wind forces) in the Phase 1 Project:

Baseline Criteria. Low-threat applications where high-vulnerability (i.e., low-resistance) systems are acceptable.

These baseline criteria are within the ISC categories of FSL I and II, ASHRAE Guideline 29 LORs of negligible and minor, and NRC LOPs of LP-1 and LP-3. As indicated in Tables 2 and 3 in Appendix C.2, only four requirements are specified for FSL I and II that pertain to building enclosures and the related HVAC interactions:

- Provide procedures for emergency shut-down, shelter-in-place (SIP), and evacuation.
- Secure accessible air intake grilles from tampering or removal.
- Develop written procedures for the emergency shut-down or exhaust of air handling systems.
- Protect the system controls from unauthorized access.

However, additional baseline criteria are recommended for compliance with ASHRAE Guideline 29,[13] NRC-2007,[14] PBS P100-2010,[22] and ASHRAE Standard 62.1,[23] as shown in Tables 2 and 3 in Appendix C.2, and Column M of page 2 in Appendix C.1.

Benchmark Criteria (P+). Moderate-threat applications where high to moderate vulnerability systems are acceptable.

These benchmark criteria are within the ISC category of FSL III, ASHRAE Guideline 29 LOR of moderate, and NRC LOPs of LP-2 and LP-3. As indicated in Table 4 in Appendix C.2, one of the four requirements specified for FSL I and II has been modified and six requirements have been added that pertain to building enclosures and the related HVAC interactions:

- Secure accessible air intake grilles with fencing (modified).
- Monitor air intake grilles with CCTV monitoring or guard patrols.
- Provide separate isolated HVAC systems in lobbies, loading docks, mail rooms, and other locations susceptible to CBR attack (i.e., external release) that are isolated from other building areas.
- Use Minimum Efficiency Reporting Value (MERV) 10 particulate filter on all exterior AHUs for biological filtration of general building.
- Use MERV 13 particulate filter on all AHUs in mailrooms and lobbies for biological filtration.
- Install an emergency shut-off and exhaust system for air handlers.

- Control movement of elevators and close applicable doors and dampers to seal building.

Additional P+ criteria are recommended for compliance with ASHRAE Guideline 29,[13] NRC-2007,[14] PBS P100-2010,[22] and ASHRAE Standard 62.1,[23] as shown in Table 4 in Appendix C.2, and Column N of page 2 in Appendix C.1.

Benchmark Criteria (P++). High-threat applications where moderate- to low-vulnerability (i.e., high-resistance) systems are required.

These benchmark criteria are within the ISC category of FSL IV, ASHRAE Guideline 29 LOR of serious, and NRC LOPs LP-2 and LP-4. As indicated in Table 5 in Appendix C.2, two of the seven requirements specified for FSL III have been modified and three requirements have been added that pertain to building enclosures and the related HVAC interactions:

- Place air intakes on rooftop or on walls at least 30 feet or 3 stories above grade (Modified).
- Use Minimum Efficiency Reporting Value (MERV) 13 particulate filter on all AHUs, including the supply air stream for recirculating AHUs in mailrooms and lobbies, and for biological filtration of general building (Modified).
- Ensure that the enclosure of the isolated loading docks and mail room is full-height construction and is sealed to the floor, roof or ceiling above.
- Provide Intrusion Detection System (IDS) coverage of ventilation equipment and control rooms.
- Provide an emergency response module to the building's energy management system (i.e., EMS/BAS) to switch the system to a prescribed emergency response mode.

Additional P++ criteria are recommended for compliance with ASHRAE Guideline 29,[13] NRC-2007,[14] PBS P100-2010,[22] and ASHRAE Standard 62.1,[23] as shown in Table 5 in Appendix C.2, and Column P of page 2 in Appendix C.1.

Benchmark Criteria (Future/HP). Very High-threat applications where very low-vulnerability (i.e., very high-resistance) systems are required.

These benchmark criteria are within the ISC category of FSL V, ASHRAE Guideline 29 LOR of critical, and NRC LOPs of LP-2 and LP-4. As indicated in Table 6 in Appendix C.2, one of the five requirements specified for FSL IV has been modified and four requirements have been added that pertain to building enclosures:

- Use HEPA filters or functional equivalents (i.e., MERV 17 – 20) on AHUs serving critical areas, mailrooms and lobbies, including outside ones (AHUs) and in the supply air stream of recirculating AHUs (Modified).
- Provide gas adsorption filters on recirculated air as well as on outside air intakes which serve critical areas.
- Provide two or more redundant locations for one-step shut-off and exhaust system for air handlers.
- Provide instrumentation to monitor pressure relationship established by the isolated systems.
- Install CBR detection technology to protect critical areas against known credible threats.

Additional Future/HP criteria are recommended for compliance with ASHRAE Guideline 29,[13] NRC-2007,[14] PBS P100-2010,[22] and ASHRAE Standard 62.1,[23] as shown in Table 6 in Appendix C.2, and Column Q of page 2 in Appendix C.1.

Whole-Building Energy Utilization Targets

EISA-2007 established an aggressive plan for reducing energy utilization in public and private sector buildings with the goal of achieving energy independence (e.g., zero net energy) in new commercial and federal buildings by the year 2030 (see Title IV, Sections 422, 431, and 433).[1] For new and major renovations of larger federal buildings, EISA-2007, Section 433, mandated the following reductions in "fossil fuel-generated energy consumption" compared to the 2003 data in the Commercial Buildings Energy Consumption Survey (CBECS-2003):[24] 65% by 2010; 80% by 2020; and 100% by 2030.

For consistency with this goal, while providing standardized information on the thermal characteristics of building enclosures, the Architectural and Mechanical Committees have chosen the ASHRAE Standard 90.1 series,[19-20] ASHRAE Standard 189.1-2009,[36] and the ASHRAE Advanced Energy Design Guide[21] as the basis for evaluating the thermal performance of the enclosures and for selecting whole-building energy utilization targets. ASHRAE Standards 90.1-2004[19] and 90.1-2010[20] specify acceptable thermal performance characteristics for enclosure assemblies in 17 climatic zones (Section 5), provide prescriptive procedures with which to estimate whole-building energy cost and consumption (Section 11) for a specific project, and provide procedures with which to compare performances of alternative designs with a site-specific baseline of energy consumption (Appendix G).

In a series of studies,[25, 26] the Pacific Northwest National Laboratory (PNNL) has simulated building performance in buildings modeled to exceed the ASHRAE Standard 90.1-2004 by 50% and have provided estimated Energy Utilization Intensity (EUI) values for each of the climatic zones, but these values do not include system or energy use adjustments needed to accommodate CBR protection. For the Phase 1 Project, these studies therefore provided the basis for selecting the whole-building energy utilization targets at minimum/low CBR protection (i.e., FSL I/II). These studies concluded that compliance with ASHRAE Standard 90.1-2010 would result in a 30% reduction in energy use compared to 90.1-2004, and inferred that compliance with ASHRAE Standard 90.1-2010 is consistent with a 65% reduction compared to the CBECS data, which EISA-2007 requires by 2015 for federal buildings.

For the Phase 1 OPR, the baseline and benchmark criteria for whole-building energy utilization have been defined in terms of targets, as actual site-specific energy modeling is not within the scope of Phase 1, and such targets are appropriate for planning purposes (see Section 1.9 of P100-2010[22]). These targets address four climatic zones, as defined in ASHRAE Standards 90.1-2004 and 90.1-2010 (i.e., CZ 1-2, CZ 3-4, CZ 5-6, and CZ 7-8), and three levels of energy performance in office buildings, as shown on Columns D-F on pages 1-4 of Appendix C.3). These combinations have resulted in four categories of whole-building energy targets, from which baseline and three levels of benchmark (i.e., P+, P++, and Future/HP) criteria have been defined that are consistent with those for other sub-attributes (i.e., CBR protection, external blast, external ballistics, seismic and wind forces) in the Phase 1 Project:

Baseline Target. The expected value of annual Energy Utilization Intensity (i.e., EUI in Btu/Gross ft^2 of floor area) and percentage of the annual EUI attributable to the enclosure when the building is designed in compliance with ASHRAE Standard 90.1-2004 for the climatic zone.

Benchmark Target (P+). The expected value of annual EUI and percentage of annual EUI attributable to the enclosure when the building is designed in compliance with ASHRAE Standard 90.1-2010 (i.e., 30% below ASHRAE Standard 90.1-2004) for the climatic zone.

Benchmark Target (P++). The expected value of annual EUI and percentage of annual EUI attributable to the enclosure when the building is designed in compliance with the ASHRAE Advanced Energy Design

Guide for Small to Medium Office Buildings[21] (i.e., 50% below ASHRAE Standard 90.1-2004) for the climatic zone.

Benchmark Target (Future/HP). The expected value of annual EUI and percentage of annual EUI attributable to the enclosure when the building is designed in compliance with goal to achieve zero-net-energy (ZNE) (see Title IV, sections 401(20) and 422)[1] for the climatic zone by:

- Reducing the annual EUI to at least 10% below the P++ target (a judgment value selected by the Architectural and Mechanical Committees);
- Off-setting the residual annual EUI with renewable energy sources that do not produce green house gases (GHG) to achieve a net zero annual EUI (i.e., no consumption of fossil fuels);
- Minimizing the emission of GHG from the residual EUI; and
- Employing “economically viable” technologies.

Environmental Footprint

An environmental (i.e., ecological) footprint is a “measure of human demand on the Earth's ecosystems that is based on consumption and pollution.”[27] Emissions from fossil fuel-generated energy consumption contribute to the environmental footprint. These emissions include gases from combustion processes that absorb and emit radiation within the thermal infrared range, which is a fundamental cause of the “greenhouse effect.”[28] One of the most prevalent of these gases is carbon dioxide (CO_2).

EISA-2007 requires reduction of GHG in its definition of ZNE but does not elsewhere address environmental footprints or GHG reductions for public and private sector buildings. However, The US EPA does provide guidance.[29]

For the Phase 1 OPR, the baseline and benchmark criteria for the environmental footprint have been defined in terms of equivalent CO_2 (CO_2e) targets that are calculated from the corresponding whole-building energy utilization targets. These CO_2e targets address four climatic zones, as defined in ASHRAE 90.1-2004 and 90.1-2010 for thermal transfer across building enclosures (i.e., CZ 1-2, CZ 3-4, CZ 5-6, and CZ 7-8), three assumed levels of electricity and fuel mix,[7] as shown in Columns G-I on page 1 of Appendix C.3, and three levels of energy performance in office buildings, as shown on Columns D-F on page 1 of Appendix

C.3. These combinations have resulted in four categories of environmental footprint targets, which define the baseline and three levels of benchmark (i.e., P+, P++, and Future/HP) criteria that are consistent with those for other sub-attributes (e.g., CBR protection, external blast, external ballistics, seismic and wind forces) in the Phase 1 Project:

Baseline Target. The calculated value of annual CO_2e and percentage of annual CO_2e attributable to the enclosure when the building is designed in compliance with ASHRAE Standard 90.1-2004 for the climatic zone and electricity/fuel mix.

Benchmark Target (P+). The calculated value of annual CO_2e and percentage of annual CO_2e attributable to the enclosure and percentage attributable to the enclosure when the building is designed in compliance with ASHRAE Standard 90.1-2010 (i.e., 30% below ASHRAE Standard 90.1-2004) for the climatic zone and electricity/fuel mix.

Benchmark Target (P++). The calculated value of annual CO_2e and percentage of annual CO_2e attributable to the enclosure when the building is designed in compliance with the ASHRAE Advanced Energy Design Guide for Small to Medium Office Buildings[21] (i.e., 50% below ASHRAE Standard 90.1-2004) for the climatic zone and electricity/fuel mix.

Benchmark Target (Future/HP). The calculated value of annual CO_2e and percentage of annual CO_2e attributable to the enclosure when the building is designed in compliance with goal to achieve ZNE (see Title IV, sections 401(20) and 422)1 for the climatic zone and electricity/fuel mix.

Renewable Energy

EISA-2007 requires the use of "renewable energy sources that do not produce green house gases" as part of its goal to achieve ZNE in new commercial and federal buildings by the year 2030 (see Title IV, Sections 422, 432, and 433).[1] This requirement excludes the use of biofuels and other processes that involve combustion (i.e., produces GHG), and essentially limits the choice of on-site renewable energy devices to solar photovoltaic panels, solar thermal panels, and wind turbines.

For the Phase 1 OPR, baseline and benchmark targets for renewable energy production have been defined in terms of surface areas of roof-mounted solar photovoltaic flat-plate panels to provide the equivalent annual electrical requirements for lighting and plug loads corresponding to the whole-building utilization targets for baseline, P+ and P++

performance levels, and for provision of the residual EUI at the Future/HP performance level. These renewable energy targets address four climatic zones, as defined in ASHRAE 90.1-2004 and 90.1-2010 for thermal transfer across building enclosures (i.e., CZ 1-2, CZ 3-4, CZ 5-6, and CZ 7-8), the corresponding e-GRID region[7] and estimated PV solar radiation availability at the site,[11] as shown in Columns C, G and H of Appendix C.3, and three levels of energy performance in office buildings, as shown on Columns D-F of Appendix C.3. These combinations have resulted in four categories of renewable energy targets, from which baseline and three levels of benchmark (i.e., P+, P++, and Future/HP) criteria have been defined that are consistent with those for other sub-attributes (e.g., CBR protection, external blast, external ballistics, seismic and wind forces) in the Phase 1 Project:

Baseline Target. The expected value of the PV-plate area (SF) to GSF ratio for Lighting and Plug Loads when the building is designed in compliance with ASHRAE Standard 90.1-2004 for the climatic zone and solar radiation availability.

Benchmark Target (P+). The expected value of the PV-plate area (SF) to GSF ratio for Lighting and Plug Loads when the building is designed in compliance with ASHRAE Standard 90.1-2010 (i.e., 30% below ASHRAE Standard 90.1-2004) for the climatic zone and solar radiation availability.

Benchmark Target (P++). The expected value of the PV-plate area (SF) to GSF ratio for Lighting and Plug Loads when the building is designed in compliance with the ASHRAE Advanced Energy Design Guide for Small to Medium Office Buildings[21] (i.e., 50% below ASHRAE Standard 90.1-2004) for the climatic zone and solar radiation availability.

Benchmark Target (Future/HP). The expected value of the PV-plate area (SF) to GSF ratio for all of the residual EUI when the building is designed in compliance with goal to achieve ZNE (see Title IV, sections 401(20) and 422)[1] for the climatic zone and solar radiation availability.

Metrics and Outcomes

Metrics and estimated outcomes have been characterized in Appendices C.1-C.3, with which to evaluate compliance with the baseline or benchmark criteria for: 1) **CBR protection** from external releases; 2) **energy utilization** and **environmental footprint** and their attributable percentages to the building enclosure; and 3) the opportunity to offset these energy and environmental footprint impacts with roof-mounted photovoltaic arrays. The parameters and values of the metrics have been selected so that they can be used for validation during design and verification during operations.

CBR Protection

Metrics for direct evaluation of CBR protection require measurement of occupant exposure to externally released CBR agents through methods that identify the agents and quantify their concentrations over time on both sides of the building enclosure boundary. Instrumentation needed to provide this direct evaluation is available on a very limited basis and, due to its cost and complexity, is primarily utilized for critical applications, such as National Special Security Events (NSSE) and Olympic Games.[30] For the Phase 1 OPR, a qualitative metric for occupant exposure has been defined in Column H of Appendix C.1 (i.e., Low, Medium, High) and the quantitative metric has only been considered for Future/HP Benchmark performance category (i.e., FLS V).

In accordance with federal law and regulations, and published standards and guidance documents that are the foundation for the baseline and benchmark criteria,[12-18, 22, 23, 32, 33] metrics for indirect evaluation of CBR protection have been defined in Phase 1 for enclosure integrity, make-up air filtration, and enclosure pressurization control.

Envelope Integrity

Shown as part of the thermal load in Column I of Appendix C.1, the indirect metric for CBR protection across the enclosure assemblies is the mass transfer rates of air and water vapor, lb/hr - ft^2 through opaque and glazed surface areas. CBR agents are assumed to be transported in the air or water vapor across the enclosure assemblies according to the equation shown in Tables 2 – 6 in Appendix C.3, which is a form of Eqn. 18 in the ASHRAE Fundamentals[37]:

$$\mathbf{Q_c = M_o A_o \Delta P_{i\text{-}l}} \qquad [1]$$

where: Q_c is the air or water vapor mass transfer rate, lb/hr - ft_2;

M_o is the air leakage factor or water vapor permeability factor across the enclosure assembly, lb/hr-ft^2-in. w.g.;

A_o is the surface area of the enclosure assembly, ft^2; and

$\Delta P_{i\text{-}o}$ is the positive or negative air pressure or partial pressure of water vapor difference across the enclosure assembly, in. w.g.

Equation [1] may also be used as a metric for estimating natural ventilation rates, where M_o is characterized by the size and placement of the operable windows or other portals. Refer to the Architectural and Fenestration Technical Reports for additional information.

Make-up Air Intake Filtration

As shown in Column I of Appendix C.1 and in Tables 2 – 6 in Appendix C.2, the indirect metric for CBR protection through make-up air intakes is the mass removal rate by filtration of CBR agents, evaluated according to the equation:[31]

Equation

$$\mathbf{E = V \sum \varepsilon_i c_i} \qquad [2]$$

where: E is the removal rate of the CBR agents (or surrogates), µg/hr;

V is the volumetric airflow rate of the make-up air intake being filtered, m^3/hr;

ε_i is the removal efficiency of each agent or surrogate, i, in terms of mass of gas or vapor (e.g., toxins) or particulates (e.g., bacteria), or number counts of particles, that do not penetrate through the filter as tested by the manufactures in accordance with relevant standards[32, 33]:

Equation

$$\mathbf{\varepsilon_i = (1 - c_{d,i}/c_i)} \qquad [3]$$

where: c_i is the concentration of agent (or surrogate) upstream of the filter, $\mu g/m^3$ or count/m3; and

$c_{d,i}$ is the concentration of the agent (or surrogate) downstream of the filter, $\mu g/m^3$ or count/m^3.

Envelope Pressurization Control

As shown in Column I of Appendix C.1 and Tables 2 – 6 in Appendix C.2, the indirect metric for CBR protection through enclosure pressurization control provided by the make-up air (i.e., part of the HVAC system) is either the perimeter zone differential air pressure across enclosure, $\Delta P_{i\text{-}o}$, in. w.g., or the differential between supply and exhaust airflow rates for the perimeter zones, $\Delta P_{s\text{-}r}$, in. w.g. (i.e., pressure-tracking) or $\Delta V_{s\text{-}r}$, m^3/hr or ft^3/min (i.e., flow-tracking).

Estimated Outcomes

For the four performance categories of CBR Protection (i.e., Baseline, P+, P++, and Future/HP), estimated outcomes in terms of the metrics for indirect evaluation are shown in Columns M – Q of Appendix C.1 and Tables 2 - 6 in Appendix C.2. The corresponding estimated outcomes, in terms of vulnerability, are shown in Columns R – U of Appendix C.1:

- **Baseline.** Envelope integrity and make-up air particulate air filters (i.e., MERV 8 - 13)[32] are to be in compliance with ASHRAE Standard 90.1-2004. No chemical filtration of make-up air and no active pressurization control for the perimeter zones or enclosure is provided. The expected performance outcome is High CBR Vulnerability, as shown in Column R of Appendix C.1.
- **Benchmark P+.** Envelope integrity and make-up air particulate air filters (i.e., MERV 9 - 13) are to be in compliance with ASHRAE Standard 90.1-2010. Also to be provided is chemical filtration of make-up air with low to medium efficiency (e.g., 30 - 60%) and appropriate impregnated activated carbon,[13, 33] and active pressurization control (Δ10% difference between make-up and exhaust airflow rates) of the filtered make-up air is provided to the perimeter zones when fenestrations are closed during occupied and unoccupied conditions[22] The expected performance outcome is Moderate to Low CBR Vulnerability when fenestrations are closed but High Vulnerability when fenestrations are open (e.g., natural ventilation), as shown in Column S of Appendix C.1.
- **Benchmark P++.** Envelope integrity is to be in compliance with ASHRAE 50% AEDG,[21] make-up air particulate air filters are to be MERV 13 - 17 and chemical filters are to be medium to high efficiency (e.g., 60 - 95%) with appropriate impregnated activated carbon,13 and active pressurization control (e.g., > 0. 05 in w.g. difference between inside to outside air pressures) is provided across all enclosure surfaces when fenestrations are closed during occupied and unoccupied conditions. The expected performance outcome is Low CBR Vulnerability when fenestrations are closed but High Vulnerability when fenestrations are open (e.g., natural ventilation), as shown in Column T of Appendix C.1.
- **Benchmark Future/HP.** Envelope integrity is to be in compliance with ASHRAE AEDG Guide,21 make-up air particulate air filters are to be MERV > 17 (e.g., HEPA) and chemical filters are to be high

efficiency (e.g., > 95%) with appropriate impregnated activated carbon,[13] active pressurization control (> 0. 05 in w.g. difference between inside to outside air pressures) is provided across all enclosure surfaces when fenestrations are closed, CBR detection technology is installed to protect critical areas against known credible threats,[12] and control strategies are installed for system shut-downs without exacerbating occupant exposure to externally released CBR agents.[13] The expected performance outcome is Very Low CBR Vulnerability when fenestrations are closed but High Vulnerability when fenestrations are open (e.g., natural ventilation), as shown in Column U of Appendix C.1.

Energy Utilization and Environmental Footprint

Energy Utilization Intensity

A common metric for evaluating whole-building energy utilization is the Energy Utilization Intensity, EUI, which is a measure of the annual building energy consumption, normalized for gross floor area (GSF)[22, 24] of the building. Typically, the annual EUI is modeled, or derived from twelve contiguous monthly readings from the utility meters for the building (e.g., natural gas, electricity, other), converted to a common energy dimension (e.g., Btu), totalized, and normalized by the gross floor area of the building (e.g., Btu/GSF/yr).[21, 22, 24, 26, 34] In accordance with published standards and guidance documents that are the foundation for the baseline and benchmark criteria, this metric was selected for the Phase 1 OPR as shown in Column H of Appendix C.1 and Columns D - F on pages 1-4 of Appendix C.3.

Related metrics for the Phase 1 OPR are the amount and percentage of EUI available for heat dissipation across the opaque and glazed surface areas of the enclosure. These metrics are shown in Columns V – AA on page 4 of Appendix C.3.

Equivalent CO_2 Emission (CO_2e)

For the Phase 1 OPR, the metric for the environmental footprint from the building has been selected as the equivalent mass emission rate of carbon dioxide, CO_2e, per GSF (with dimensions of lb-CO_2/GSF/yr). This metric is calculated, but not measurable, from the EUI and the regional mix of non-renewable site energy resources, as shown in Column H of Appendix C.1 and Columns L - N on page 1 of Appendix C.3.[7, 29]

A related metric for the Phase 1 OPR is the amount of CO_2e attributable to heat dissipation of the opaque and glazed surface areas of the enclosure. This related metric is shown in Columns AB – AD on page 4 of Appendix C.3.

Estimated Outcomes

For the four performance categories of energy consumption and environmental footprint (i.e., Baseline, P+, P++, and Future/HP) and in terms of the metrics shown in Columns M – Q of Appendix C.1, the corresponding estimated outcomes, in terms of vulnerabilities of energy and CO_2e, are shown in Columns R – U in page 2 of Appendix C.1:

- **Baseline.** For compliance with ASHRAE Standard 90.1-2004 without enhanced CBR protection, the EUI should not exceed the target value for the climatic zone, and the CO_2e emission rate should not exceed that corresponding to the EUI and the assumed fuel mix value. Outcomes for six examples are shown in Columns D, G, and L on page 1 of Appendix C.3.
  - To achieve an energy balance for the building while complying with 90.1-2004, the percentages of EUI and CO_2e attributable to the heat dissipation of the enclosure loads should not exceed the target values, as shown for six examples on page 4 of Appendix C.3 in Columns V or Y for the attributable EUI and in Column AB for the attributable CO_2e.
  - The expected baseline performance outcomes are Moderate Energy and CO_2e Vulnerabilities and High CBR Vulnerability as shown in Column R of Appendix C.1.
  - To reduce the CBR vulnerability (i.e., increase the CBR benchmark performance to P+ or higher), modifications to the building enclosure, make-up air filtration and pressurization control will be needed, which will impact the baseline energy target either positively or negatively. Therefore: 1) the proposed and baseline designs for compliance with ASHRAE Standard 90.1-2004, Section 11 or Appendix G,[19] will have to be modified; 2) the baseline EUI and CO_2e target values will have to be adjusted from those shown in Columns D, and V or Y on page 4 of Appendix C.3; and 3) the expected performance outcomes will have to be re-evaluated.

Quantitative examples of revised baseline EUI and CO_2e target values for increased CBR protection (i.e., P+, P++ and Future/HP) have not been provided, as energy modeling is required, which is outside the scope of Phase 1.

- **Benchmark P+.** For compliance with ASHRAE Standard 90.1-2010 (i.e., 30% energy reduction from 90.1-2004) without enhanced

CBR protection, the EUI should not exceed the target value for the climatic zone and the CO_2e emission rate should not exceed that corresponding to the EUI and assumed fuel mix value. Outcomes for six examples are shown in Columns E, H, and M on page 1 of Appendix C.3.

- To achieve an energy balance for the building while complying with 90.1-2010, the percentages of EUI and CO_2e attributable to the heat dissipation of the enclosure loads should not exceed the target values, as shown for six examples on page 4 of Appendix C.3 in Columns W or Z for the attributable EUI, and in Column AC for the attributable CO_2e.
- The expected P+ performance outcomes are Moderate to Low Energy Vulnerabilities, as shown in Column S of Appendix C.1, but High CBR Vulnerability (i.e., Baseline performance for CBR, Column R)
- To reduce the CBR vulnerability (i.e., increase the CBR benchmark performance to P+ or higher), modifications to the building enclosure, make-up air filtration and pressurization control will be needed, which will impact the P+ energy target either positively or negatively. Therefore: 1) the proposed and baseline designs for compliance with ASHRAE Standard 90.1-2010, Section 11 or Appendix G,[20] will have to be modified; 2) the P+ EUI and CO_2e target values will have to be adjusted from those shown in Columns E, and W or Z on page 4 of Appendix C.3; and 3) the expected performance outcomes will have to be re-evaluated.

Quantitative examples of revised P+ EUI and CO_2e target values for increased CBR protection (i.e., P+, P++ and Future/HP) have not been provided, as energy modeling is required, which is outside the scope of Phase 1.

- **Benchmark P++.** For compliance with the ASHRAE 50% AEDG[21] (i.e., 50% energy reduction from 90.1-2004) without enhanced CBR protection, the EUI should not exceed the target value for the climatic zone and the CO_2e emission rate should not exceed that corresponding to the EUI and assumed fuel mix value. Outcomes for six examples are shown in Columns F, I, and N on page 1 of Appendix C.3.
  - To achieve an energy balance for the building while complying with the ASHRAE 50% AEDG, the percentages of EUI and CO_2e attributable to the heat dissipation of the enclosure loads should not exceed the target values, as shown for six examples on page

4 of Appendix C.3 in Columns X or AA for the attributable EUI, and in Column AD for the attributable CO_2e.

- The expected P++ performance outcomes are Moderate to Low Energy Vulnerabilities, as shown in Column T of Appendix C.1, but High CBR Vulnerability (i.e., Baseline performance for CBR, Column R).
- To reduce the CBR vulnerability (i.e., increase the CBR benchmark performance to P+ or higher), modifications to the building enclosure, make-up air filtration and pressurization control will be needed, which will impact the P++ energy target either positively or negatively. Therefore: 1) the proposed and baseline designs for compliance with the ASHRAE 50% AEDG[21] and ASHRAE Standard 90.1-2010, Section 11 or Appendix G,[20] will have to be modified; 2) the P++ EUI and CO_2e target values will have to be adjusted from those shown in Columns F, and X or AA on page 4 of Appendix C.3; and 3) the expected performance outcomes will have to be re-evaluated.

Quantitative examples of revised P++ EUI and CO_2e target values for increased CBR protection (i.e., P+, P++ and Future/HP) have not been provided, as energy modeling is required, which is outside the scope of Phase 1.

- **Benchmark Future/HP.** For compliance with the goal to achieve ZNE (see Title IV, sections 401(20) and 422)1 without enhanced CBR protection, the EUI should be at least 10% below the P++ target value for the climatic zone. This residual EUI is to be achieved by the use renewable energy sources that do not produce green house gases (i.e., zero CO_2e emission rate).
  - The expected Future/HP performance outcome is Low Energy and CO_2e Vulnerabilities, as shown in Column U of Appendix C.1, but High CBR Vulnerability (i.e., Baseline performance for CBR, Column R).
  - To reduce the CBR vulnerability (i.e., increase the CBR benchmark performance to P+ or higher), modifications to the building enclosure, make-up air filtration and pressurization control will be needed, which will impact the Future/HP energy performance, either positively or negatively. Therefore: 1) the proposed and baseline designs for compliance with the 50% ASHRAE AEDG[21] and ASHRAE Standard 90.1-2010, Section 11 or Appendix G,[20] will have to be modified; and 2) the expected performance outcomes will have to be re-evaluated.

Quantitative examples of revised Future/HP EUI and CO_2e target values for increased CBR protection (i.e., P+, P++ and Future/HP) have not been provided, as energy modeling is required, which is outside the scope of Phase 1.

Roof-Mounted Photovoltaic Arrays

For the Phase 1 OPR, the ratio of PV panel surface area (SF) to GSF is the metric selected to evaluate the opportunity to offset energy and environmental footprint target values by using renewable energy sources that do not produce green house gases (i.e., roof-mounted photovoltaic arrays).

Estimated Outcomes

For three of the four performance categories of renewable energy sources (i.e., Baseline, P+, and P++), the estimated outcomes in terms of ranges of the PV-plate area (SF) to GSF ratios needed to provide the electrical power for lighting and plug loads are shown in Columns R – Y of Appendix C.3 for six example locations of climatic zone and solar availability.

For the Future/HP category, the estimated outcomes could only be inferred in Phase 1. Based on the estimates in Columns N – P of Appendix C.3, the lighting and plug loads represent approximately 30% of the EUIs for the six examples. Therefore, based on these percentages and assuming that the residual EUIs should be 10% less than for the P++ category, the estimated PV-plate area (SF) to GSF ratios needed to offset all of the residual EUIs for a ZNE building are approximately two times larger than the ratios for the lighting and plug loads in the P++ category.

The vulnerabilities for the PV panel arrays are shown in Columns R – U in page 2 of Appendix C.1. To reduce the CBR vulnerability (i.e., increase the CBR benchmark performance to P+ or higher) while maintaining the performance categories for the PV array, modifications to the building enclosure, make-up air filtration and pressurization control will be needed, which will impact the EUIs and the corresponding the PV-plate area (SF) to GSF ratios. Also, the vulnerabilities of depending on the use of the PV sub-system during extraordinary conditions require the need for extra protection for the PV array and installation of redundant systems. Therefore: 1) the proposed and baseline designs for compliance with ASHRAE Standard 90.1-2004 or 90.1-2010, Section 11 or Appendix G,19-21 will have to be modified; 2) the PV-plate area (SF) to GSF ratios will have to be adjusted from those shown in Columns R - Y on page 4 of Appendix C.3; and 3) the expected outcomes will have to be re-evaluated.

Quantitative examples of revised Future/HP PV-plate area (SF) to GSF ratios for increased CBR protection (i.e., P+, P++ and Future/HP) have not been provided, as energy and economic modeling is required, which is outside the scope of Phase 1.

Systems for Meeting Demand/Resisting External CBR Releases (i.e., Threat)

The Mechanical Committee's objective in Phase 1 has been to evaluate means and methods of reducing the risk of occupant exposure to externally released CBR agents that penetrate the building enclosure. This evaluation has focused on: 1) the interactions of building sub-systems that are capable of impeding the transport of these agents across the building enclosure and into occupied spaces; 2) the impacts of these sub-systems on energy utilization and carbon footprint attributable to the building enclosure; and 3) the opportunity to offset these impacts with roof-mounted photovoltaic arrays. The characteristics of the enclosure and HVAC sub-systems that were used in this evaluation are described in this section.

Description of System Characteristics

Columns K and L of Appendix C.1 identify the general characteristics of these building enclosure and HVAC sub-systems, respectively. More specific baseline and benchmark characteristics of these sub-systems are shown in Columns M – Q of Appendix C.1 and Tables 2 – 6 in Appendix C.2. Generally, these sub-systems have been characterized in terms of compliance with the relevant ASHRAE Standards,[19-20] and supplemented with more rigorous requirements and recommendations as indicated by other Standards and Guidelines.[12-18, 21-23, 32-33] Characteristics, which pertain to CBR protection from external releases and to energy utilization, are described in this Report; additional building enclosure characteristics are described in the other Technical Reports.

Baseline System Characteristics

The enclosure and HVAC sub-systems for the baseline performance are assumed to provide minimal protection from externally released CBR agents (i.e., FSL categories I and II, as indicated in Table 1 of Appendix C.2) while meeting the baseline energy target in accordance with ASHRAE Standard 90.1-2004,[25, 26] as shown in Column D of Appendix C.3, pages 1-4, for six example locations.

Envelope Sub-System

- The heat transfer and thermal load characteristics of the proposed enclosure assemblies are assumed to be in compliance with the Budget Building Design in Section 11 or with the Baseline Building Performance in Appendix G of ASHRAE 90.1-2004, including fenestration sizes, locations, and schedules of openings. The Architectural and Fenestration Technical Reports provide additional information.
- Air leakage through the proposed enclosure assemblies is assumed to be in compliance with Section 5.4.3 of ASHRAE 90.1-2004 when the fenestrations are closed (see Tables 2 and 3, Appendix C.2). The Architectural Technical Report provides additional information.
- Moisture transfer across the proposed enclosure assemblies is not addressed in ASHRAE 90.1-2004, but is assumed to be in qualitative compliance with Section 5.14.1 of ASHRAE 62.1-2010. The Architectural Technical Report provides additional information.
- Natural ventilation sub-assemblies (i.e., open fenestrations and other portals) are not addressed in ASHRAE 90.1-2004, but are assumed to be in compliance with Section 6.4 of ASHRAE 62.1-2010, including allowance of permanent openings and controls for energy management. No controls for CBR protection have been assumed. The Fenestration Technical Report provides additional information.
- Damper air leakage for the proposed make-up air intakes and exhaust air discharges is assumed to be in compliance with Section 6.4.3.3.4 of ASHRAE 90.1-2004, but the dampers are not assumed to be tightly sealed for CBR protection.

HVAC Sub-System

- The non-customized HVAC sub-system is assumed to be limited to the specific Budget Building Design options in Section 11.3.2 and Figure 11.3.2 and Table 11.3.2A in Section 11, or the Baseline Building Performance options in Section G3 and Tables G3.1, G3.1.A and G3.1.1B in Appendix G of ASHRAE 90.1-2004.
- Make-up air filtration is addressed indirectly in Section 6.5.3.1 and Appendix G3.1.2.9 in ASHRAE 90.1-2004, in terms of adjustments for allowable fan power; values for filter efficiencies are not addressed. For the baseline HVAC sub-system, the impact of the filters on the target EUI value is assumed to be negligible.
  - Particulate air filter efficiencies (e.g., MERV 8 -13) for the make-up air stream are assumed to be in compliance with Section 6.2.1 of ASHRAE 62.1-2010, Section 5.8 of PBS-P100-2010 and Section 5.4.3.1 of ASHRAE 29-2009 (also see Tables 2 and 3, Appendix C.2).

  - No chemical air filtration devices are assumed to be in the make-up air stream (see Column M, Appendix C.1, and Tables 2 and 3 in Appendix C.2).

- Outdoor air ventilation system controls are assumed to be in compliance with Section 6.4.3.3 of ASHRAE 90.1-2004 to reduce energy utilization, and the outdoor air ventilation rates are in compliance with Section 6.2.1 of ASHRAE 62.1-2010.

- As an option, roof-mounted flat-plate solar photovoltaic panels, tilted south at angle equal to latitude, are assumed to be interfaced with the building enclosure for power production with a 15% conversion efficiency (i.e., interface to grid, parallel AC and DC service, and some battery backup) to provide the equivalent annual electrical requirements for lighting and plug loads corresponding to the whole-building utilization targets for baseline performance (see Columns I, R and V of Appendix C.3).

- Control Strategies

  - Active pressurization control for perimeter zones is not addressed in ASHRAE 90.1-2004 or in ASHRAE 62.1-2010. To the contrary, Section 6.4.3 of 90.1-2004 requires control strategies to shut down systems to save fan power, which could exacerbate enclosure integrity for CBR protection.[13, 14] No perimeter zone pressurization control has been assumed for the baseline condition. (Column M, Appendix C.1).

  - An active detection, monitoring and control system for CBR protection has not been assumed for the baseline control strategies. However, the baseline system is assumed to have the following control features, in accordance with Section 5.18 of PBS P100-2010 (see Tables 2 and 3, Appendix C.2):

    - An interface between BAS, fire/smoke, elevator safety, lighting, and security control systems in accordance with life-safety codes.

    - Control strategies and oversight monitoring through the BAS to manage indoor environmental quality (e.g., thermal, lighting, acoustics, and contaminant exposures), sustainability goals, and energy consumption during normal conditions, in accordance with owner's program requirements.

P+ System Characteristics

The proposed enclosure and HVAC sub-systems for P+ performance are assumed to be capable of providing a moderate level of protection from externally released CBR agents (i.e., FSL category III, as indicated in Table 1 of Appendix C.2) while providing up to 30% reduction in energy consumption compared to ASHRAE 90.1-2004. This P+ performance will require modifications to the energy targets from those shown on pages 1-4 in Column E of Appendix C.3 for the six example locations through energy modeling of the sub-systems, in accordance with Section 11.3 or G3 in ASHRAE 90.1-2010, to accommodate the CBR protection enhancements.

The following sub-system characteristics are assumed to have been achieved in accordance with the P+ performance requirements for blast, ballistic, seismic, floor, fire, and wind effects, as described in the other Technical Reports.

Envelope Sub-System

- The heat transfer and thermal load characteristics of the proposed enclosure assemblies are in compliance with Budget Building Design in Section 11 or with the Baseline Building Performance in Appendix G of ASHRAE 90.1-2010, including fenestration sizes, locations, and schedules of openings. The Architectural and Fenestration Technical Reports provide additional information.
- Air leakage through the proposed enclosure assemblies is in compliance with Section 5.4.3 of ASHRAE 90.1-2010 and Section 5.4.2.12 of ASHRAE 29-2009 when the fenestrations are closed (see Table 4, Appendix C.2). The Architectural Technical Report provides additional information.
- Moisture transfer across the proposed enclosure assemblies is not addressed in ASHRAE 90.1-2010, but is assumed to be in qualitative compliance with Section 5.14.1 of ASHRAE 62.1-2010. The Architectural Technical Report provides additional information.
- Natural ventilation sub-assemblies are operational and in compliance with Section C5.6 and Table G3.1 of 90.1-2010 and Section 6.4 of ASHRAE 62.1-2010, including allowance of permanent openings, during normal conditions.
  - Passive control strategies are capable of closing all natural ventilation sub-assemblies for protection from external CBR releases, in accordance with Section 5.4.3.1.4 of ASHRAE 29-2009. The Fenestration Technical Report provides additional information.
- Make-up air intakes are located “away from public accessible areas, preferably at the roof level or at exterior walls of high-rise buildings” and free from “obstructions near the intakes that might conceal a contaminant delivery device,” in accordance with Section

5.8 of PBS P100-2010 and Section 5.4.2.11 of ASHRAE 29-2009 for Moderate Risk.

- Damper air leakage for make-up air intakes and exhaust air discharges is addressed in Section 6.4.3.4.3 of ASHRAE 90.1-2010, but these allowable values do not provide seals that are any tighter than 90.1-2004. For P+ performance, all make-up and exhaust air dampers are motorized and the leakage rates are 50% less than those shown in Table 6.4.3.4.3 of ASHRAE 90.1-2010 when tested in accordance with AMCA Standard 500.[35]

HVAC Sub-System

- The semi-customized HVAC sub-system (i.e., Proposed Building Design) is based on the Budget Building Design options from Figure 11.3.2 and Table 11.3.2A in Section 11, or with the Baseline Building Performance options from Tables G3.1, G3.1.A and G3.1.1B in Appendix G of ASHRAE 90.1-2010, but modified to provide moderate CBR protection.
- Make-up air for ventilation and zone pressurization is provided by a filtered Dedicated Outside Air Sub-system (DOAVS) with 50% energy recovery of exhaust air in accordance with Section 6.5.6.1 of ASHRAE 90.1-2010.
- Separate isolated air-handling units (AHU) with DOAVS and energy recovery devices are provided for lobbies, loading docks, mail rooms, and other locations susceptible to CBR attack (i.e., external release) that are isolated from other building areas, in accordance with ISC-2009, page A-10,12 Section 5.4.4 of ASHRAE 29-2009, and Section 5.6 of PBS P100-2010.
- Make-up air filtration is addressed indirectly in Section 6.5.3.1.1 and Appendix G3.1.2.10 in ASHRAE 90.1-2010, in terms of adjustments for allowable fan power; values for filter efficiencies are not addressed. The increase in the P+ energy target value is assumed to be moderate (e.g., 2 – 5%).
  - Particulate air filters (e.g., MERV 9 - 13) for the make-up air stream are in compliance with Section 6.2.1 of ASHRAE 62.1-2010, Section 5.8 of PBS-P100-2010, and Section 5.4.3.1 of ASHRAE 29-2009 (see Column N, Appendix C.1, Table 4, Appendix C.2).
  - Chemical air filtration devices with low to medium efficiency (e.g., 30 - 60%) and appropriate impregnated activated carbon, are provided in the make-up air stream, in accordance with Section 5.4.3.1 of ASHRAE 29-2009 (see Column N, Appendix C.1, and Table 4 in Appendix C.2).

- Outdoor air ventilation system controls for energy management are in compliance with Section 6.4.3.4 of ASHRAE 90.1-2010, and the outdoor air ventilation rates are in compliance with Section 6.2.1 of ASHRAE 62.1-2010.
- As an option, roof-mounted flat-plate solar photovoltaic panels, tilted south at angle equal to latitude, are interfaced with the building enclosure for power production with a 15% conversion efficiency (i.e., interface to grid, parallel AC and DC service, and some battery backup) to provide the equivalent annual electrical requirements for lighting and plug loads corresponding to the whole-building utilization targets for P+ performance (see Columns I, S and W of Appendix C.3).
- Control System and Strategies:
    - Active pressurization control of filtered make-up air for perimeter zones is provided in compliance with Section 6.4.3.3.4 of ASHRAE 90.1-2010, Section 5.4.3.1.4 of ASHRAE 29-2009, and Section 5.3 of PBS P100-2010 (see Column N, Appendix C.1 and Table 4 in Appendix C.2):
- For each isolated perimeter zone, a 10% differential airflow rate is controlled between supply and exhaust air streams, when windows are other natural ventilation ports are closed during occupied and unoccupied periods, by either flow-tracking (i.e., ΔVs-r, m3/hr or ft3/min) or by pressure-tracking (i.e., ΔPs-r, in. w.g.), accounting for interzonal pressurization requirements, fixed and variable exhaust air requirements, and building enclosure tightness.
    - Active detection (i.e., sensing) and control to minimize exposure to CBR agents has not been assumed for the P+ control strategies. However, the P+ system is assumed to have the following control features in accordance with Section 5.18 of PBS P100-2010, ISC-2009, and ASHRAE 29-2009 (see Table 4 in Appendix C.2):
        - An interface between BAS, fire/smoke, elevator safety, lighting, and security control systems in accordance with life-safety codes.
        - Control strategies for system shut-downs without exacerbating occupant exposure to externally released CBR agents.
        - Oversight monitoring and control capabilities through the BAS to manage indoor environmental quality (e.g., thermal, lighting, acoustics, and contaminant exposures), sustainability goals, and energy consumption during normal conditions, in accordance with owner's program requirements.

- Monitoring capabilities of air intake grilles with CCTV.
- An emergency shut-off and exhaust system procedure for air handing units.
- Control of movement of elevators and closures of applicable doors and dampers to seal building.

P++ System Characteristics

The proposed enclosure and HVAC sub-systems for P++ performance are assumed to be capable of providing a high level of protection from externally released CBR agents (i.e., FSL category IV, as indicated in Table 1 of Appendix C.2) while providing up to 50% reduction in energy consumption compared to ASHRAE 90.1-2004 for FSL IV CBR protection. This P++ performance will require modifications to the energy targets from those shown on pages 1-4 in Column F of Appendix C.3 for the six example locations through energy modeling of the sub-systems, in accordance with Section 11.3 or G3 in ASHRAE 90.1-2010, to accommodate the CBR protection enhancements,.

The following sub-system characteristics are assumed to have been achieved in accordance with the P++ performance requirements for blast, ballistic, seismic, floor, fire, and wind effects, as described in the other Technical Reports.

Envelope Sub-System

- The heat transfer and thermal load characteristics of the proposed enclosure assemblies are in compliance with the reductions in the Budget Building Design in Section 11 or with the Baseline Building Performance in Appendix G of ASHRAE 90.1-2010, as modified by ASHRAE Section 7.4.2 of ASHRAE 189.1-2009[36] and the ASHRAE 50% AEDG,[21] including fenestration sizes, locations, and schedules of openings. The Architectural and Fenestration Technical Reports provide additional information.
- Air leakage through the proposed enclosure assemblies is in compliance with Section 5.4.3 of ASHRAE 90.1-2010 as modified by ASHRAE Section 7.4.2.10 of ASHRAE 189.1-2009[36] and the ASHRAE 50% AEDG[21], and with Section 5.4.2.12 of ASHRAE 29-2009 when the fenestrations are closed (see Table 4, Appendix C.2). The Architectural Technical Report provides additional information.
- Moisture transfer across the proposed enclosure assemblies is not addressed in ASHRAE 90.1-2010 or ASHRAE 189.1-2009, but is assumed to be in qualitative compliance with Section 5.14.1 of ASHRAE 62.1-2010, and with Chapter 5, par EN-23, of the ASHRAE

50% AEDG. The Architectural Technical Report provides additional information.

- Natural ventilation sub-assemblies are operational and in compliance with Section C5.6 and Table G3.1 of 90.1-2010, Table D3.1 (Schedules) in 189.1-2009, and Section 6.4 of ASHRAE 62.1-2010, including allowance of permanent openings, during normal conditions. The ASHRAE 50% AEDG advocates extensive use of natural ventilation as an energy reducing strategy during normal conditions, but does not address the vulnerabilities and risks of opened natural ventilation ports during an external CBR release. The Fenestration Technical Report provides additional information on vulnerabilities and risks of natural ventilation related to blast and other threats.
  - To reduce vulnerability to external CBR releases, windows and other natural ventilation sub-assemblies are capable of closing rapidly and tightly.
  - Active (i.e., feedback control) and passive (i.e., monitoring) control strategies are used to close all natural ventilation sub-assemblies in anticipation of external CBR releases in accordance with Section 5.4.3.1.4 of ASHRAE 29-2009, Page 52 of ISC-2009, and LP-4 level of protection in accordance with NRC-200714 (see Table 1, Appendix C.2).
- Make-up air intakes are located on the rooftop or on walls at least 30 feet or 3 stories above grade, in accordance with Page 52 of ISC-2009, and away from public accessible areas and free from obstructions near the intakes that might conceal a contaminant delivery device, in accordance with Section 5.8 of PBS P100-2010, Section 5.4.2.11 of ASHRAE 29-2009 for High Risk.
- All make-up and exhaust air dampers are motorized and the leakage rates are 75% less than those shown in Table 6.4.3.4.3 of ASHRAE 90.1-2010 when tested in accordance with AMCA Standard 500.[35]
- Envelope sub-assemblies of the isolated loading docks and mail room are full-height construction and are sealed to the floor, roof or ceiling above, in accordance with ISC-2009 (see Table 5, Appendix C.2).

HVAC Sub-System

- The customized HVAC sub-system (i.e., Proposed Building Design) is based on the recommendations in the ASHRAE 50% AEDG,[21, 25, 26] but modified to provide high CBR protection.
- Make-up air for ventilation and zone pressurization is provided by a filtered Dedicated Outside Air Sub-system (DOAVS) with 70 - 75%

energy recovery of exhaust air in accordance with the Section 5.8 of PBS P100-2010 and HV10 and HV 12 in Chapter 5 of ASHRAE 50% AEDG.

- Separate isolated air-handling units (AHU) with DOAVS and energy recovery devices are provided for lobbies, loading docks, mail rooms, and other locations susceptible to CBR attack (i.e., external release) that are isolated from other building areas, in accordance with ISC-2009, page A-10,[12] Section 5.4.4 of ASHRAE 29-2009, and Section 5.6 of PBS P100-2010.
- Make-up air filtration is addressed indirectly in Section 6.5.3.1.1 and Appendix G3.1.2.10 in ASHRAE 90.1-2010, in terms of adjustments for allowable fan power; values for filter efficiencies are not addressed. The increase in the P++ energy target value is assumed to be significant (e.g., 5 – 10%).
  - Particulate air filters (e.g., MERV 13 - 17) for the make-up air stream are in compliance with Section 6.2.1 of ASHRAE 62.1-2010, Section 5.8 of PBS-P100-2010, and Section 5.4.3.1 of ASHRAE 29-2009 (see Column P of Appendix C.1, and Table 5 of Appendix C.2).
  - Chemical air filtration devices with medium to high efficiency (e.g., 60 - 95%) and appropriate impregnated activated carbon, are provided in the make-up air stream, in accordance with Section 5.4.3.1 of ASHRAE 29-2009 (see Column P of Appendix C.1, and Table 5 of Appendix C.2).
- Outdoor air ventilation system controls for energy management, including demand/control ventilation (DCV), are in compliance with Section 6.4.3.4 of ASHRAE 90.1-2010, Section 7.4.3.2 of ASHRAE 189.1-2009, the ASHRAE 50% AEDG, and Section 5.18 of PBS P100-2010. The outdoor air ventilation rates are assumed to be in compliance with Section 6.2.1 of ASHRAE 62.1-2010.
- As an option, roof-mounted flat-plate solar photovoltaic panels, tilted south at angle equal to latitude, are interfaced with the building enclosure for power production with a 15% conversion efficiency (i.e., interface to grid, parallel AC and DC service, and some battery backup) to provide the equivalent annual electrical requirements for lighting and plug loads corresponding to the whole-building utilization targets for P++ performance (see Columns I, T and X of Appendix C.3).
- Control System and Strategies:
  - Active pressurization control of filtered make-up air for perimeter zones is provided in compliance with Section 6.4.3.3.4

of ASHRAE 90.1-2010, Section 5.4.3.1.4 of ASHRAE 29-2009, Section 5.3 of PBS P100-2010, and NRC-200714 (see Column P, Appendix C.1 and Tables 1 and 5 in Appendix C.2):

- For each isolated perimeter zone, a differential air pressure, $\Delta P_{i\text{-}o}$, of at least 0. 05 in w.g. is assumed to be controlled between the inside and outside surfaces of all enclosure assemblies, when windows are other natural ventilation ports are closed during occupied and unoccupied periods, accounting for interzonal pressurization requirements, fixed and variable exhaust air requirements, building enclosure tightness, and dynamic wind effects.

- An Intrusion Detection System (IDS) provides coverage of ventilation equipment and control rooms, perimeter entry and exit doors, and all windows within 16 feet of the ground or other access point, in accordance with page 64 of ISC-2009.
  - Monitor at an on-site central station during operating hours, and off-site after hours.
- An active detection (i.e., sensing) and control system to minimize exposure to CBR agents has not been assumed for the P++ control strategies. However, the P++ system is assumed to have the following control features in accordance with Section 5.18 of PBS P100-2010, ISC-2009, and ASHRAE 29-2009 (see Table 5 in Appendix C.2):
  - An emergency response module to the building's energy management system (i.e., BAS) is provided to switch the system to a prescribed emergency response mode.
  - An interface between BAS, fire/smoke, elevator safety, lighting, and security control systems in accordance with life-safety codes.
  - Control strategies for system shut-downs without exacerbating occupant exposure to externally released CBR agents. A one-step shut-off and exhaust system is provided for air handlers.
  - Oversight monitoring and control capabilities through the BAS to manage indoor environmental quality (e.g., thermal, lighting, acoustics, and contaminant exposures), sustainability goals, and energy consumption during normal conditions, in accordance with owner's program requirements.
  - Monitoring capabilities of air intake grilles with CCTV.

- Control of movement of elevators and closures of applicable doors and dampers to seal building.

Future/HP System Characteristics

The proposed enclosure and HVAC sub-systems for Future/HP performance are assumed to be capable of providing a very high level of protection from externally released CBR agents (i.e., FSL category V, as indicated in Table 1 of Appendix C.2) while achieving a ZNE performance (see Title IV, sections 401(20) and 422, EISA-2007).[1] This performance will require modifications to the energy targets from those shown on pages 1-4 in Column F of Appendix C.3 for the six example locations through energy modeling of the sub-systems to achieve the CBR protection enhancements in accordance with FSL V in ISC-2009 and Critical Risk Category in ASHRAE Standard 29-2009 (see Table 6 in Appendix C.2), while achieving ZNE performance, through changes in enclosure and HVAC sub-system characteristics including the application of a solar photovoltaic sub-system to meet the residual EUI target.

The following sub-system characteristics are assumed to have been achieved in accordance with the Future/HP performance requirements for blast, ballistic, seismic, floor, fire, and wind effects, as described in the other Technical Reports.

Envelope Sub-System

- The proposed enclosure assemblies result in an additional 10% reduction in annual average thermal loads (see Column Q of Appendix C.1) compared to the Budget Building Design in Section 11 or with the Baseline Building Performance in Appendix G of ASHRAE 90.1-2010, as modified by ASHRAE Section 7.4.2 of ASHRAE 189.1-2009[36] and the ASHRAE 50% AEDG.[21] The Architectural and Fenestration Technical Reports provide additional information.

- Air leakage through the proposed enclosure assemblies is 10% less than is required for compliance with Section 5.4.3 of ASHRAE 90.1-2010 as modified by ASHRAE Section 7.4.2.10 of ASHRAE 189.1-2009[36] and the ASHRAE 50% AEDG,[21] and with Section 5.4.2.12 of ASHRAE 29-2009 when the fenestrations are closed (see Table 4, Appendix C.2). The Architectural Technical Report provides additional information.

- Moisture transfer is in compliance with ASHRAE 62.1-2010 and the ASHRAE 50% AEDG. The Architectural Technical Report provides additional information.

- Natural ventilation sub-assemblies are operational and in compliance with Section C5.6 and Table G3.1 of 90.1-2010, Table D3.1 (Schedules) in 189.1-2009, and Section 6.4 of ASHRAE 62.1-2010 during normal conditions, but permanent (i.e., non-closeable) openings are not allowed. The ASHRAE 50% AEDG advocates extensive use of natural ventilation as an energy saving strategy during normal conditions but does not address the vulnerabilities and risks of opened natural ventilation ports during an external CBR release. The Fenestration Technical Report provides additional information on vulnerabilities and risks of natural ventilation related to blast and other threats.
  - To reduce vulnerability to external CBR releases, the number and sizes of operable windows and other natural ventilation sub-assemblies are minimal.
  - Those sub-assemblies that are installed are capable of closing rapidly and tightly.
  - Active (i.e., feedback control) and passive (i.e., monitoring) control strategies are used to close all natural ventilation sub-assemblies in anticipation of external CBR releases in accordance with Section 5.4.3.1.4 of ASHRAE 29-2009, Page 52 of ISC-2009, and LP-4 level of protection in accordance with NRC-2007[14] (see Table 1, Appendix C.2).
- Make-up air intakes are located on the rooftop or on walls at least 30 feet or 3 stories above grade, in accordance with Page 52 of ISC-2009, and away from public accessible areas and free from obstructions near the intakes that might conceal a contaminant delivery device, in accordance with Section 5.8 of PBS P100-2010, and Section 5.4.2.11 of ASHRAE 29-2009 for Very High Risk.
- All make-up and exhaust air dampers are motorized and the leakage rates are 90% less than those shown in Table 6.4.3.4.3 of ASHRAE 90.1-2010 when tested in accordance with AMCA Standard 500.[35]
- Envelope sub-assemblies of the isolated loading docks and mail rooms are full-height construction and are sealed to the floor, roof or ceiling above, in accordance with ISC-2009 (see Table 6, Appendix C.2).

HVAC Sub-System

- The customized HVAC sub-system (i.e., Proposed Building Design) is based on achieving the whole-building energy target, ZNE, which is derived from the recommendations in the ASHRAE 50% AEDG,[21, 25, 26] to meet the EISA-2007[1] requirements, but modified to provide very high CBR protection.

- Make-up air for ventilation and zone pressurization is provided by a filtered Dedicated Outside Air Sub-system (DOAVS) with 70 - 75% energy recovery of exhaust air in accordance with the Section 5.8 of PBS P100-2010 and HV10 and HV 12 in Chapter 5 of ASHRAE 50% AEDG.
- Separate isolated air-handling units (AHU) with DOAVS and energy recovery devices are provided for lobbies, loading docks, mail rooms, and other locations susceptible to CBR attack (i.e., external release) that are isolated from other building areas, in accordance with ISC-2009, page A-10,12 Section 5.4.4 of ASHRAE 29-2009, and Section 5.6 of PBS P100-2010.
- Make-up air filtration is addressed indirectly in Section 6.5.3.1.1 and Appendix G3.1.2.10 in ASHRAE 90.1-2010, in terms of adjustments for allowable fan power; values for filter efficiencies are not addressed. The increase in the P++ energy target value is assumed to be significant (e.g., 10 – 20%).
    - Particulate air filters (e.g., MERV 17 - 20, HEPA) for the make-up air stream to critical zones are in compliance with page 52 of ISC 2009, Section 6.2.1 of ASHRAE 62.1-2010, Section 5.8 of PBS-P100-2010, and Section 5.4.3.1 of ASHRAE 29-2009 (see Column Q, Appendix C.1, Table 6, Appendix C.2).
    - Chemical air filtration devices with high efficiency (e.g., > 95%) and appropriate impregnated activated carbon, are provided in the make-up air stream, in accordance with page 52 of ISC-2009 and Section 5.4.3.1.2 of ASHRAE 29-2009 (see Column Q, page 2 of Appendix C.1, and Table 5 in Appendix C.2).
- Outdoor air ventilation system controls for energy management, including demand/control ventilation (DCV), are in compliance with Section 6.4.3.4 of ASHRAE 90.1-2010, Section 7.4.3.2 of ASHRAE 189.1-2009, the ASHRAE 50% AEDG, and Section 5.18 of PBS P100-2010. The outdoor air ventilation rates are in compliance with Section 6.2.1 of ASHRAE 62.1-2010.
- In compliance with the EISA-2007,[1] flat-plate solar photovoltaic panels, tilted south at angle equal to latitude, are located on the roof and other on-site locations for power production with a 15% conversion efficiency (i.e., interface to grid, parallel AC and DC service, and significant battery storage and backup) to provide, within the owner's cost-effectiveness criteria, the energy for the residual EUI to approach ZNE performance during normal occupied and unoccupied conditions (see Columns I, U and Y of Appendix C.3).

- Control System and Strategies:
  - Active pressurization control for perimeter zones is provided in compliance with Section 6.4.3.3.4 of ASHRAE 90.1-2010, Section 5.4.3.1.4 of ASHRAE 29-2009, Section 5.3 of PBS P100-2010, and NRC-200714 (see Column P of Appendix C.1, and Tables 1 and 6 in Appendix C.2):
    - A separate air distribution system is provided for each pressurization zone, including public areas, in accordance with Section 5.4.3.1.2 of ASHRAE 29-2009.
    - For each isolated perimeter zone, a differential air pressure, ΔPi-o, of at least 0. 05 in w.g. is assumed to be controlled between the inside and outside surfaces of all enclosure assemblies, when windows are other natural ventilation ports are closed during occupied and unoccupied periods, accounting for interzonal pressurization requirements, fixed and variable exhaust air requirements, building enclosure tightness, and dynamic wind effects.
    - For protection from an external CBR release, some HVAC systems are program to continue to run for occupant protection. Make-up air dampers for zones that have been directly attacked are programmed to close while make-up air dampers for zones that have not been directly attacked are programmed to open to maintain zone pressurization, in accordance with Section 5.4.3.1.4 of ASHRAE 29-2009.
  - An Intrusion Detection System (IDS) provides coverage of ventilation equipment and control rooms, perimeter entry and exit doors, and all windows within 16 feet of the ground or other access point, in accordance with page 64 of ISC-2009.
    - Monitor at an on-site central station during operating hours, and off-site after hours.
    - Monitor pressure relationship established by the isolated systems.
  - An active detection (i.e., sensing) and control system to minimize exposure to CBR agents is provided, in accordance with LP-4 level of protection in NRC-2007 (see Tables 1 and 6, Appendix C.2). In addition, the Future/HP system has the following control features in accordance with Section 5.18 of PBS P100-2010, ISC-2009, and ASHRAE 29-2009 (see Table 6 in Appendix C.2):

- An emergency response module to the building's energy management system (i.e., BAS) is provided to switch the system to a prescribed emergency response mode.
- An interface between BAS, fire/smoke, elevator safety, lighting, and security control systems in accordance with life-safety codes.
- Control strategies for system shut-downs without exacerbating occupant exposure to externally released CBR agents. A one-step shut-off and exhaust system is provided for air handlers in accordance with Page 52 of ISC-2009.
- Oversight monitoring and control capabilities through the BAS to manage indoor environmental quality (e.g., thermal, lighting, acoustics, and contaminant exposures), sustainability goals, and energy consumption during normal conditions, in accordance with owner's program requirements.
- Monitoring capabilities of air intake grilles with CCTV.
- Control of movement of elevators and closures of applicable doors and dampers to seal building.
- Control capabilities to manage energy utilization and CBR protection during normal and extraordinary conditions (i.e., resiliency).

Discussion

The primary purpose of the enclosure and HVAC sub-systems, as described in this Report, is to integrate CBR protection with the other attributes and sub-attributes of High Performance Buildings. Within the Phase 1 scope, the focus of the Mechanical Committee has been on evaluating: 1) the capabilities of the interactions of these sub-systems to impede the transport of externally released CBR agents across the building enclosure and into occupied spaces; 2) the impacts of these integrated sub-systems on energy utilization and carbon footprint attributable to the building enclosure; and 3) the opportunity to cost-effectively reduce fossil fuel use and emissions of greenhouse gases by offsetting these impacts with roof-mounted photovoltaic arrays.

Two methods of passive control (i.e., resistance of air and moisture transfer through the building enclosure, and filtration of make-up air) and two methods of active control (i.e., air pressurization control of perimeter zones; and sensing, monitoring and control strategies) have been identified to impede transportation of non-specific CBR agents across the building enclosure and into occupied spaces. Although the uncertainties of these methods are not well-defined or quantified, these methods are being required by ISC-2009[12] and recommended by other standards and guidelines[13-18] at specified levels of protection (LOP)

CBR protection also requires removal of externally released airborne agents, which have penetrated the building enclosure, by transporting them to centralized or local filtration sub-systems within the building. HVAC interactions for removal of CBR agents that penetrate the building enclosure, and those that are released within the building, are dependent on the air distribution performance of the whole HVAC system, the analysis of which was outside the scope of this phase of the project.

The sets of enclosure and HVAC sub-system characteristics, as described in the preceding section, represent integrated solutions for the four levels of performance (i.e., baseline, P+, P++, and Future/HP) and assume compliance with all of the corresponding performance criteria. However, the expected outcomes, as described in the Metrics and Outcomes section, are disaggregated in terms of the metrics for CBR protection, energy utilization and environmental footprint, and roof-mounted PV arrays. Therefore, significant additional uncertainties exist in expected outcomes.

These uncertainties can be analyzed through modeling and simulation of the proposed integrated systems for specific cases, and compared to those used as references[25, 26] (i.e., validation through case/control studies) and through modeling and comparison with actual performance data (i.e., verification through post-occupancy evaluations, such as NIBS-2008[38]).

Estimates of Performance for Sub Attributes

The performance outcomes for sub-systems described in the section on Metrics and Outcomes have been estimated from individual sub-attributes, with energy criteria as a basis[19-21] and supplemented with CBR protection criteria,[12-18] from minimal CBR protection at the baseline level of performance, FSL I/II, to very high level of CBR protection at the Future/HP level of performance, FSL V. Conversely, the section on Description of System Characteristics integrates the CBR protection and the energy/environment criteria and requirements for sub-systems at each combined level of performance (i.e., baseline, P+, P++ and Future/HP).

System Performance Matrix

A matrix of performance outcomes for sets of building enclosure and HVAC sub-systems, with and without the solar PV option, is shown in Table 1. The bold numbers with green background represent sub-systems with baseline level CBR protection for which estimates of energy and environmental footprint performance outcomes are provided in Appendix C.3. The bold-italicized numbers with red background represent the integrated sub-systems in the section on Description of System Characteristics for which compliance is assumed with all of the criteria for the combined levels of CBR and energy/environmental footprint performance. All other sub-systems in the matrix depend on additional modeling and simulations, as described for reducing CBR vulnerabilities in the Expected Outcomes sub-section of Metrics and Outcomes, which is outside the scope of Phase 1. As examples: Set #1 represents an enclosure/HVAC sub-system that does not have the PV option, and is intended to provide Baseline Energy/Environment performance and Baseline CBR Protection; Set #7A represents and enclosure/HVAC sub-system that provides the PV option, and is intended to provide a P+ level of Energy/Environment performance and a P++ level of CBR Protection.

Table 1: Matrix of Envelope and HVAC Sub-systems at each Performance Level for CBR Protection and Energy/Environmental Impact, with and without Optional Solar PV Sub-systems.

Level of Performance Energy/Environment CBR Protection	Baseline		P+		P++		Future/HP	
	No PV	Optional PV	No PV	Optional PV	No PV	Optional PV	No PV	Optional PV
Baseline	**1**	**1a**	**5**	**5a**	**9**	**9a**	**13**	**13a**
	1	***1a***						
P+	2	2a	***6***	***6a***	10	10a	14	14a
P++	3	3a	7	7a	***11***	***11a***	15	15a
Future/HP	4	4a	8	8a	12	12a	***16***	***16a***

Interpretation of Estimates

Resistance to External CBR Releases

The lack of exposure data precludes analysis of system performance for quantitative estimates of levels or risk (LOR) or levels of protection (LOP). Furthermore, this lack of data severely limits evaluation of active control strategies to minimize occupant exposure, and substantially increases the level of uncertainty regarding the nexus of protecting the occupants and facilities from CBR attacks[12] while reducing energy consumption during normal conditions.[1]

In lieu of direct control of exposure, indirect control through passive and active resistance is being used in practice. Passive resistance to the transport of externally released CBR agents includes increasing the integrity of the thermal and moisture transfer characteristics of the building enclosure, reducing air leakage through the make-up air dampers, and placing air filtration devices in the make-up air streams as described in the section on Metrics and Outcomes. Active resistance is limited to pressurization control of perimeter zones when fenestrations are closed, except for the FSL V category, which requires detection (i.e., sensing) and control for suspected CBR agents.[12] Uncertainties associated with passive and active resistance control strategies are large as they depend not only on the design but also on the maintenance and operations of the facility staff and motivation of the occupants.

Energy Utilization and Environment Footprint

Ranges of EUI and CO_2e Whole-Building Target Values

Energy targets for buildings with sub-system types 1, 5, and 9 in Table 1 are shown in Columns D-F on pages 1-4 of Appendix C.3 for six example climatic locations. Corresponding calculations of CO_2e emission rates are shown in Column L on page 1. Each of these sub-system types is assumed to have the baseline level of CBR protection.

The ranges of EUI target values for these example locations and corresponding CO_2e emission rates are:

- Baseline energy and CBR performance for sub-system type 1 = 46-70 kBtu/GSF/yr and 9-25 lb/GSF/yr of CO_2e.
- P+ energy performance but baseline CBR performance for sub-system 5 = 31-43 kBtu/GSF/yr and 6-15 lb/GSF/yr of CO_2e.
- P++ energy performance but baseline CBR performance for sub-system 9 = 22-31 kBtu/GSF/yr and 4-11 lb/GSF/yr of CO_2e.
- Future/HP energy performance but baseline CBR performance for sub-system 13 is assumed as 20-28 kBtu/GSF/yr and 3-10 lb/GSF/yr of CO_2e (i.e., approximately 10% less than for the P++ level of performance).

The buildings and their sub-systems in the section on Description of Building Characteristics (i.e., types 1, 6, 11, and 16 in Table 1) are assumed to be capable of complying with these energy target ranges, which will be revised upwards or downwards from the baseline values, while simultaneously complying with the corresponding CBR performance (i.e., baseline = FSL I/II, P+ = FSL III, P++ = FSL IV and Future/HP = FLS V). The validity of this assumption is uncertain, but further evaluation is outside the scope of Phase 1.

These baseline and presumed benchmark EUI target values are substantially lower than the 24-year average energy consumption rates in the CBECS database for office buildings of 104 kBtu/GSF/yr, and the target values for benchmarks P++ and Future/HP are substantially below the validated EUIs of 40 – 132 kBtu/GSF/yr from 19 office buildings reported by NCEMBT that were constructed or renovated since 1988.[34] These comparisons reveal the challenge ahead in achieving, validating, and verifying simultaneous energy reduction and CBR protection at the benchmark performance levels (P+, P++, and Future/HP).

Ranges of EUI and CO2e Target Values Attributable to the Building Envelope

As shown in Columns Y-AD on page 4 of Appendix C.3, the percentages of EUIs attributable to the opaque and glazed surfaces of the enclosures were calculated as the residual values from energy balances that account for direct consumption of the energy resources for lighting, plug loads, and service water heating, in addition to the energy required to dissipate the heat from the internal and ventilation loads. The corresponding CO_2e emission rates were calculated from the residual EUI values.

The target ranges of EUI percentages attributable to the enclosures for the example locations and the corresponding CO_2e emission rates are:

- Baseline performance for sub-system type 1 = 4-23% of the EUI and <1–6 lb/GSF/yr of CO_2e.
- P+ energy performance but baseline CBR performance for sub-system 5 = 1-24% of EUI and <1–3 lb/GSF/yr of CO_2e.
- P++ energy performance but baseline CBR performance for sub-system 9 = 6-30% of EUI and <1–3 lb/GSF/yr of CO_2e.
- Future/HP energy performance but baseline CBR performance for sub-system 13 is assumed at 6-30% of EUI and <1–3 lb/GSF/yr of CO_2e (i.e., approximately the same percentages as for the P++ level of performance).

The buildings and their sub-systems in the section on Description of Building Characteristics (i.e., types 1, 6, 11, and 16 in Table 1) are assumed to be capable of complying with these same percentages attributable to the building enclosure.

These outcomes indicate that, if the energy balances reported in the literature[25, 26] are valid, the percentages of EUI allocated to the enclosure (i.e., targets) should not exceed 5-6% of the whole building EUIs in moderate climates or 25-30% in more severe climates, as shown in Columns Y-AA on page 4 of Appendix C.3. A comparison of the estimates in Columns S-U with those in Y-AA also indicates that these targets can be increased by employing energy efficient technologies to other sub-assemblies, such as incorporating energy recovery equipment in the DOAVS, as shown by comparing Columns S and U with Columns Y and AA. This ability to shift the component weights within the energy balance for a constant EUI target is very important when compensating for design changes to the enclosure to accommodate enclosure resistance to blast or CBR threats.

Roof-Mounted Photovoltaic Arrays

The energy production targets for the sub-systems with optional PV (i.e., 1a, 5a, and 9a in Table 1) were assumed to be those required to offset the lighting and plug loads, as shown in Columns N-Q of Appendix C.3; the energy production target for required sub-system 13a was assumed to be that required by EISA-2007 for the residual EUI (90% of the values in Column F). The maximum and minimum PV plate surface areas to GSF ratios, which were calculated to offset these loads, are shown in Columns R-Y of Appendix C.3 for six climatic locations.

The ranges of PV plate surface area to GSF ratios for these example locations are:

- Baseline performance for sub-system type 1a = 0.4 – 0.6.
- P+ performance for sub-system 5a = 0.2 – 0.4.
- P++ performance for sub-system 9a = 0.2 – 0.3.
- Future/HP performance for sub-system 13a = 0.3 – 0.5.

The buildings and their sub-systems in the section on Description of Building Characteristics (i.e., types 1a, 6a, 11a, and 16a in Table 1) are assumed to be capable of complying with these same offset targets and area ratios while simultaneously complying with the corresponding CBR performance (i.e., baseline, P+, P++ and Future/HP).

These energy production targets and plate area to GSF ratios indicate that the roof-mounted PV option may be applicable for one or two-story buildings, but this option is problematic for taller buildings. Although the application of this option provides the capability of offsetting the consumption of fossil fuels to meet the EUI requirements, it does not reduce the required capacity or schedule of operations of the HVAC sub-systems. Reliable benchmark performance of the HVAC sub-systems for CBR protection requires the use of redundant energy resources. This requirement is a major potential conflict with the concept of ZNE, which requires that, if cost-effective, the residual EUI be met with renewable resources that do not produce greenhouse gases.[1]

Estimates of Cost Impacts

Preliminary estimates of the impacts that the interactions of the enclosure and HVAC sub-systems listed in Table 1 may have on first costs and maintenance and operational costs to provide for CBR protection and reduced energy consumption are based on the studies by PNNL[25, 26] and the experiences of the Mechanical Committee members.

Sub-systems with Baseline CBR Protection (FSL I/II)

Sub-systems 1, 5, 9, and 13 (see Table 1) provide increasing potentials to reduce building energy consumption and CO_2e emissions but provide only minimum/low level of CBR protection (i.e., FSL I/II, see Table 1 in Appendix C.2). The enclosure integrity, make-up air damper leakage, and particulate air filtration are assumed to be in compliance with the respective ASHRAE Standards 90.1-2004, 90.1-2010, and ASHRAE 50% AEDG. However, neither chemical filtration of make-up air nor pressurization control for the perimeter zones is provided for these sub-systems. Sub-systems 1a, 5a, 9a, and 13a provide supplemental renewable energy opportunities through the PV sub-systems to offset consumption of fossil fuels, but the capacities and schedules of the HVAC sub-systems are not impacted, so back-up energy sources are needed to assure building performance.

First Costs

Based on the PNNL studies,[25, 26] the first cost of the modeled building with sub-system 1 (i.e., compliant with ASHRAE 90.1-2004) would be expected to range from \$93 – 155/GSF for a 1-4 story office building in the 17 climatic zones. However, experience reveals that actual Class A and monumental buildings have had first costs that exceeded this range by factors of two or more.

- The estimated incremental first cost of the modeled building with sub-system 9 (i.e., compliant with ASHRAE 50% AEDG), as compared to sub-system 1, was reported to range from \$2.37 – 4.22/GSF. The estimated incremental first cost of the modeled building with sub-system 5 was not reported, but is interpolated as approximately

60% of that for sub-system 9 (i.e., 30% rather than 50% energy reduction from sub-system 1). These low incremental costs, which need to be validated, were rationalized by PNNL to be the result of reduced internal and enclosure loads, and higher energy efficiency of HVAC components including a DOAVS with energy recovery in sub-systems 5 and 9.

- The incremental first cost of sub-system 13 (i.e., compliant with ZNE in EISA-2007) that is needed to achieve the assumed reduction in the EUI of an additional 10% from sub-system 9 may be substantial due to the technological complexities involved. This incremental first cost was not estimated, as the modeling of how to achieve the additional energy reduction was outside the scope of Phase 1.
- As shown in Columns Z – AC of Appendix C.3, the estimated incremental costs of the PV sub-systems are $48/GSF (see columns Z-AB in Appendix C.3, page 2). for baseline energy systems (1a – 4a) and decrease to $33/GSF (see columns Z-AB in Appendix C.3, page 2) for P+ energy systems (5a-8a), and to $25/GSF (see columns Z-AB in Appendix C.3, page 2) for P++ energy systems (9a-12a) due to expected decreases in lighting loads, but increase to $32-45/GSF (see column AC in Appendix C.3, page 2) for Future/HP sub-systems (13a-16a) as all of the loads in the residual EUI must be dissipated by the PV sub-system.

Maintenance and Operations Costs

Annual whole-building energy costs were not reported in the PNNL studies but they range from approximately $1.50/GSF to more than $5.00/GSF for commercial buildings in the U.S. Annual energy cost savings with sub-system 9 compared to sub-system 1, based on the PNNL studies, are estimated to range from $0.65 – 0.89/GSF with simple paybacks ranging from 3.3 to 6.2 years for the VAV option, and 5.6 to 11.5 years for the radiant heating and cooling option.[25, 26] The estimated energy cost savings of the modeled building with sub-system 5 was not reported, but is interpolated as approximately $0.39 – 0.53/GSF (i.e., 60% of that for sub-system 9) with a simple payback of 5.5 to 10.3 years compared to sub-system 1 for the VAV system. Substantially more energy cost savings are potentially available for sub-system 13a compared to sub-systems 9a and 13, but the ranges of cost savings or payback periods have not been estimated in Phase 1.

The PNNL studies did not report estimates for other maintenance and operations costs. However, the Mechanical Committee estimates that these costs range from $2 – 4/GSF/yr for sub-system 1 with incremental increases of $2 – 3/GSF/yr for sub-system 5 and $4 – 10/GSF/yr for sub-systems 9 and 13, as shown in Column W of page 2 in Appendix C.1.

Maintenance and operations costs for sub-system 13a have not been estimated in Phase 1.

Sub-systems with Incremental Improvements in CBR Protection (FSL III - V)

All other sub-systems in Table 1 represent improvements in CBR protection (P+ = FSL III, P++ = FSL IV, and Future/HP = FSL V) at each level of energy performance.

P+ CBR Protection (FSL III)

Sub-systems 2, 6, 10, and 14 provide a moderate level of CBR protection (i.e., FSL III) while increasing the potential to reduce building energy use and CO_2e emissions. For each of these sub-systems, the enclosure integrity is upgraded for compliance with ASHRAE Standard 90.1-2010, make-up air damper leakage is reduced by 50%, chemical filtration assemblies with 30-60% efficiencies are added to the particulate filtration assemblies for the make-up air, a DOAVS with 50% energy recovery is added, perimeter pressurization with differential control of supply and return air flow rates is provided, critical perimeter zones are isolated and provided with separate HVAC sub-systems including DOAVS, and the BAS is upgraded to provide the control features required for FSL III (i.e., see Description of System Characteristics). The EUIs and CO_2e emission rates are likely to increase from the P+ target values in Column E of pages 1-4 in Appendix C.3 due to the increased CBR protection. Sub-systems 2a, 6a, 10a, and 14a provide supplemental power through the PV sub-systems to offset consumption of fossil fuels but the capacities of the HVAC sub-systems are not impacted and back-up energy sources are needed to assure building performance.

Incremental First Costs

The incremental first costs for P+ CBR protection, compared to baseline, through sub-systems 2, 6, 10, and 14 are estimated as:

- Negligible incremental first costs for upgrades in the building integrity and in tighter sealing dampers for the make-up air intakes.
- $0.50 – 1.00/SF of areas served by make-up air intake, for location away from public accessible areas, preferably at the roof level or at exterior walls of high-rise buildings and free from obstructions.
- $0.50 – 1.00/SF of area served, for chemical filtration and assemblies in the make-up air intakes.
- $1.00 – 2.00/SF of isolated area served, for each DOAVS.

- \$0.50 - \$1.00/GSF for upgrades to the BAS and differential pressure control of supply and return air flow rates.

Incremental Maintenance and Operations Costs

- \$0.50 – 1.00/GSF/yr for additional energy utilization.
- \$0.50 – 1.00/GSF/yr for replacement and servicing the particulate and chemical filters in make-up air, and for maintenance and calibration of the BAS/control system.

P++ CBR Protection (FSL IV)

Sub-systems 3, 7, 11, and 15 provide a high level of CBR protection (i.e., FSL IV) while increasing the potential to reduce building energy use and CO_2e emissions. For each of these sub-systems, the enclosure integrity is upgraded for compliance with ASHRAE Standard 189.1-2009 or the 50% AEDG, natural ventilation openings are capable of closing based on a command, make-up air damper leakage is reduced by 90%, particulate filtration efficiency is increased to MERV 13-17 and chemical filtration is increased to 60-95% efficiency for the make-up air, a DOAVS with 75% energy recovery is added, perimeter pressurization with differential control of across the enclosures is provided, critical perimeter zones are isolated and provided with separate HVAC sub-systems including DOAVS, and the BAS is upgraded to provide the control features required for FSL IV (i.e., see Description of System Characteristics). The EUIs and CO_2e emission rates are likely to increase from the P++ target values in Column F of pages 1-4 in Appendix C.3 due to the increased CBR protection. Sub-systems 3a, 7a, 11a, and 15a provide supplemental power through the PV sub-systems to offset consumption of fossil fuels but the capacities of the HVAC sub-systems are not impacted and back-up energy sources are needed to assure building performance.

Incremental First Costs

The incremental first costs for P++ compared to P+ CBR protection through sub-systems 3, 7, 11, and 15 are estimated as:

- Negligible for upgrades for the building integrity and for tighter sealing dampers for the make-up air intakes.
- \$1.00 – 2.00/SF of perimeter zones containing natural ventilation ports, for closure control in compliance with FSL IV criteria.
- \$0.50 – 1.00/SF of areas served by make-up air intake, for location on the roof or at least 30 feet above ground level.
- \$2.00 – 4.00/SF of area served by particulate and chemical filtration assemblies in make-up air.

- $1.00 – 2.00/SF of isolated area served by each DOAVS.
- $1.50 - $2.00/GSF for upgrades to the BAS and differential pressure control across enclosure surfaces.

Incremental Maintenance and Operations Costs

- $0.50 – 1.00/GSF/yr for additional energy utilization.
- $0.50 – 1.00/GSF for replacement and servicing the particulate and chemical filters in make-up air intakes, and for maintenance and calibration of the BAS/control system.

Future/HP CBR Protection (FSL V)

Sub-systems 4, 8, 12, and 16 provide a very high level of CBR protection (i.e., FSL V) while increasing the potential to reduce building energy use and CO_2e emissions. For each of these sub-systems, the enclosure integrity is upgraded for compliance with ASHRAE Standard 189.1-2009 or the 50% AEDG, natural ventilation openings are minimized and capable of closing based on feedback control signals, make-up air damper leakage is reduced by 90%, particulate filtration efficiencies are increased to MERV 17-20 (i.e., HEPA filters) and chemical filtration increased to >95% efficiency for the make-up air, a DOAVS with 75% energy recovery is added, perimeter pressurization with differential control of across the enclosures is provided, critical perimeter zones are isolated and provided with separate HVAC sub-systems including DOAVS, and the BAS is upgraded to provide the feedback and feedforward control features required for FSL V (i.e., see Description of System Characteristics). The EUIs and CO_2e emission rates are likely to increase from the Future/HP target values due to the increased CBR protection. Sub-systems 4a, 8a, 12a, and 16a provide supplemental power through the PV sub-systems to offset consumption of fossil fuels but the capacities of the HVAC sub-systems are not impacted and back-up energy sources are needed to assure building performance.

Incremental First Costs

The incremental first costs for Future/HP compared to P++ CBR protection through each of the sub-systems 4, 8, 12, and 16 are estimated as:

- Negligible for upgrades for the building integrity and for tighter sealing dampers for the make-up air intakes.
- $1.00 – 2.00/SF of perimeter zones containing natural ventilation ports, for closure control in compliance with FSL V criteria.
- $2.00 – 4.00/SF of area served, for high efficiency particulate and chemical filtration assemblies in make-up air.

- $1.00 – 2.00/SF of isolated area served by each DOAVS.
- $3.00 - $5.00/GSF for upgrades to the BAS and differential pressure control across enclosure surfaces.

Incremental Maintenance and Operations Costs

- $1.00 – 2.00/GSF/yr for additional energy utilization.
- $2.00 – 3.00/GSF/yr for replacement and servicing the particulate and chemical filters in make-up air, and for maintenance and calibration of the BAS/control system.

Description of Interactions

In the preceding section, the preliminary cost impacts of the interactions between the enclosure and HVAC sub-systems are described as discrete factors pertaining to two-way interactions involving four levels of CBR protection and four levels of energy utilization.

Functional Interactions

Consideration of these interactions was limited in the Mechanical Committee's scope of Phase 1 to those affected by the penetration of externally released CBR agents across the building enclosure, including make-up air intakes. Within this limitation, three types of functional interactions include:

- Thermal and mass transfer across the enclosure boundaries due to thermal capacitance (i.e., mass), resistance (i.e., insulation), solar radiation (i.e., daylighting), and air and water vapor transmission (i.e., infiltration and permeation) as they affect CBR protection and energy utilization.
- Natural ventilation through windows and other fenestrations (e.g., doors and other intentional penetrations), and air pressurization control at the building enclosures as they affect CBR protection and energy utilization.
- Make-up air closures (i.e., damper tightness) and need for filtered air pressurization in perimeter zones as they affect CBR protection.

This limitation significantly increases the uncertainties for achieving the expected CBR protection and energy performance, as the functional interactions associated with the transport of the released agents from the enclosure boundaries to the places of removal by filtration assemblies that are centrally located with the HVAC sub-systems, or remotely located within occupied spaces, must also be considered.[5, 13-15, 22, 31]

Other functional interactions that will affect the nexus of CBR protection and energy utilization include:

- Modifications of the building enclosure or HVAC sub-system characteristics, and locations of the HVAC sub-systems within the building, for compliance with security (e.g., blast, ballistics) and safety (e.g., flood, fire, seismic) sub-attribute criteria.
- Modifications to the energy (EUI), environmental footprint (CO_2e), and sustainability (solar PV) targets, and their percentages attributed to the building enclosure, as affected by:
  - Compliance with criteria for blast, ballistics, flood, fire, seismic, and other related security and safety sub-attributes.
  - Consideration of environmental footprint metrics, other than CO_2e emissions from combustion processes, such as embodied energy.[27-29]
  - Consideration of sustainability metrics, other than PV area/GSF, to cost-effectively comply with ZNE goals and requirements.[1]

Methods of Analysis

In Section 401 of EISA-2007[1] a high-performance building (HPB) is defined as one that "integrates and optimizes on a life-cycle basis all major high-performance attributes…" and life-cycle cost (LCC) is defined as "a technique of economic evaluation that (A) sums, over a given study period, the costs of initial investment (less resale value), replacements, operations (including energy use) and maintenance and repair of an investment decision; and (B) is expressed (i) in present value terms, in the case of a study period equivalent to the longest useful life of the building, determined by taking into consideration the typical life of such a building in the area in which the building is to be located; or (ii) in annual value terms, in the case of any other study period." These definitions require the use of an LCC model that optimizes the cost-effectiveness of all of the HPB attributes being considered for a project.

Conversely, the LCC analysis recommended in ASHRAE Standards 90.1-2004, 90.1-2010 and the 50% AEDG,[25, 26] leads to planning and design decisions that focus on predicted energy savings from pre-selected "bundles" of opportunities, assuming that the other sub-attributes are constrained to minimal effects (e.g., sub-systems 1, 5, 9, and 13 in Table 1). This type of energy-based LCC analysis is usually required for Federal Buildings.[22] LCC analyses that optimize on increased levels of performance (i.e., P+, P++ or Future/HP) for the safety, security, and sustainability attributes and sub-attributes, including their interactions, are seldom conducted for public or private commercial building projects.

Energy-based LCC analyses provide systematic methods for comparing energy-related alternatives with different streams of costs that provide the same benefits and risks (i.e., constraints) over a defined period. However, an LCC analysis without a risk-benefit analysis is incomplete and may be misleading, as it assumes no difference in costs of risks or values of benefits between options under consideration.

Risk-benefit methods utilize the results of the LCC to optimize alternatives, based on broad economic foundations.[13, 39-42] These methods account for first costs, energy costs, and other maintenance and operating costs, in conjunction with the economic benefit and risk values for the attributes and sub-attributes. Risk-benefit analyses that incorporate LCC provide more comprehensive and accurate evaluations of alternatives to achieve compliance with the set of criteria for the attributes and sub-attributes that pertain to a project during the planning and design phases.

Validation and Verification of Results

Table 1 identifies 32 combinations of sub-systems that characterize two-way interactive performance at four levels of CBR protection and four levels of energy utilization intensity (EUI). Sixteen of these sub-systems (i.e., 1 – 16) address the expected performance without supplemental solar PV sub-systems, 12 are for optional consideration (i.e., 1a – 12a) of the solar PV sub-systems, and four are for mandatory consideration to comply with ZNE requirements (i.e., 13a – 16a). In addition, the functional and economic interactions of all of the other attributes and sub-attributes will affect the nexus of CBR protection and EUI, as indicated in the preceding section on risk-benefit methods with LCC.

Quantitative functional responses of enclosure assemblies and sub-assemblies to blast, ballistics, flood, fire, wind, and thermal forces (i.e., loads) have been published from scientifically designed studies and tests that were based on standardized methodologies (see Technical Reports from the Architecture, Fenestration, Structural, and Safety Committees). Analogous results on enclosure responses to external releases of CBR agents are not available. Moreover, valid energy consumption and corresponding benefit-risk/LCC data from buildings or components such as enclosures are not available that demonstrate the nexus of CBR protection and EUI. Therefore, the estimates of functional and economic performance provided in this report should be validated and verified.

Validation Procedures

Envelope Resistance to CBR Surrogates

Explicit field data regarding the resistance of building enclosures to externally released CBR agents are not available but some field data are available on removal of CBR agents within buildings.[5] Testing and modeling during Phase 2 should be conducted to validate the predicted results for CBR penetration of the building enclosures including opaque and glazed surfaces, natural ventilation, make-up air intakes and filtration, and perimeter zone pressurization. In lieu of actual CBR agents, these validation procedures could use normal outdoor air contaminants as surrogates (e.g., water vapor, volatile organic compounds, bioaerosols, and radon) for which references to procedures and quantitative data are available, including:

- Standard laboratory and field tests for air and water vapor transport[44-47] (see Architectural and Fenestration Technical Reports).
- Laboratory and field instrumentation for testing bioaerosol transport.[48] A protocol for testing the resistance of enclosure assemblies has not been reported, but can be modified from references 44 – 47.
- Laboratory and field instrumentation for testing volatile organic compound (VOC) transport.[49] A protocol for testing the resistance of enclosure assemblies has not been reported, but can be modified from references 44 – 47.
- Laboratory and field instrumentation for testing airborne radon transport.[50] Although this protocol is for residential buildings, several of the procedures are relevant for small and medium size commercial buildings.
- Make-up air damper leakage in accordance with ANSI/AMCA Standard 500-D-07.[35]
- Standard laboratory tests for particulate and gaseous air cleaner efficiencies for the make-up air.[32, 33] As standardized field test procedures have not yet been published, protocols for these field tests will can be developed in Phase 2.

The protocols should provide for testing the enclosure resistance to each of the surrogates with and without a constant differential air pressure across the sample of the assembly or sub-assembly.

Dynamic simulations of the performance of the enclosure assemblies and sub-assemblies should be modeled with nationally recognized programs, such as CONTAM 3.0,[51] with input from the laboratory and field tests to validate the predicted CBR protection. This model should also be used to provide input to the building energy simulation model.

Energy Impacts

The predicted impacts on EUI, and percentages attributable to the building enclosures, from increased resistance to CBR transport across the building enclosure, from other enclosure-related attributes and sub-attributes (e.g., blast, ballistics, flood, wind, fire), and from contributions by the PV sub-systems should be validated in Phase 2 with dynamic simulations programs, such as EnergyPlus.[52] Before the model is used for validation, it should be "calibrated" against actual buildings and sub-systems that are similar to the project cases. This model should be interfaced with programs that simulate the performance of the CBR protection sub-attribute,[51] and the other sub-attributes that affect energy performance including the PV options (see Architecture, Fenestration, Structural, and Safety Committee Technical Reports).

Economic Impacts

Based on the validated results for CBR protection, other sub-attributes, and energy use, the first cost and operational and maintenance cost estimates for a sample set of cases (e.g., building designs) should be validated in Phase 2 by a professional cost estimator and by a professional risk manager.

Rationalization with Predicted Results

After the validation procedures are completed, the procedures for determining the predicted results should be evaluated and modified to minimize the differences in results with those obtained from the validation procedures.

Verification Procedures

Verification tests should be conducted in Phase 2 by comparing the rationalized predicted performance with the actual performance during the construction and operational phases in selected buildings (i.e., cases). For scientific integrity, an independent set of cases from the validation cases is preferable.

Protocols for the verification tests may be developed, based on those previously used by NIBS for Post-Occupancy Evaluations.[38]

Proposed Outreach Program

Based on the plans to obtain preliminary predictions, validations and verifications, an outreach/educational program should be developed and implemented in Phase 2 that focuses on scientific, technical, and practical means and methods to improve HPB design and operations for safety, health, security, efficient energy utilization, and cost-effectiveness.

Conclusions and Recommendations

The following conclusions and recommendations are provided for industry follow-up, future phases, additional research.

Preliminary Predictions of Outcomes

The predicted outcomes in Phase 1 will provide preliminary guidance to the building owner in defining a set of Owner Performance Requirements (OPR) for optimizing the sub-attributes of the building enclosure and HVAC interface for safety, security, energy, sustainability, and economic performance for a project.

CBR Protection with HVAC Interface

1. The building enclosure, which is often the first line of CBR protection against external releases, may also be one of the most vulnerable elements of a building (i.e., FSL I/II), and may account for <5 to >30% of the building energy utilization, depending on climatic conditions, implementation of energy savings technologies, and balances of energy utilization within the building.

    1.1 These outcomes indicate that, if the energy balances reported in the literature[25, 26] are valid, the percentages of EUI allocated to the enclosure (i.e., targets) should not exceed 5-6% of the whole building EUIs in moderate climates or 25-30% in more severe climates.

    1.2 These percentages can be increased, as required to accommodate resistances to blast, CBR, fire, flood, wind and other forcing functions, by employing energy efficient technologies in other sub-assemblies, such as incorporating energy recovery equipment in the DOAVS.

    1.3 **This ability to shift the component weights within the energy balance while maintaining a constant EUI target is very important when compensating for design changes to the enclosure**

to accommodate enclosure resistance to blast, CBR, or other threats.

2. Quantitative criteria for outdoor and indoor exposures to airborne CBR agents are not available in the scientific or technical literature nor are reliable CBR sensors, resulting in dependence on passive performance and classifications of risks.

   2.1 This lack of quantitative exposure criteria increases the uncertainties of the vulnerability of the building enclosure and the risk to occupants and assets.

   2.2 **A research project is needed to develop these exposure criteria and methods of measurement in terms that are analogous to those for blast, and that are understandable to the occupants and to the design teams who are responsible for optimizing the performance of the enclosure or the whole-building.**

3. In the absence of quantitative exposure criteria, qualitative criteria for level of risk (LOR) and level of protection (LOP) (i.e., Facility Security Levels FSL I to V[12]) have been identified and utilized in Phase 1.

   3.1 The FSL categories have been used as the basis for characterizing: 1) the LOP for the sub-attribute of CBR protection from external releases for various configurations of the enclosure and its interface with the HVAC sub-system; 2) the impacts of external releases and LOPs on the sub-attributes of energy utilization and environmental footprint attributable to the building enclosure; and 3) the opportunities to offset these impacts with renewable resources.

   3.2 Baseline and three levels of benchmark (i.e., P+, P++, and Future/HP) performance criteria have been defined that are consistent with those for the FSL categories and for the other sub-attributes (e.g., energy utilization, external blast, external ballistics, seismic, flood, and wind forces) in the Phase 1 Project.

4. In lieu of direct control of exposure for CBR protection, indirect control through passive and active resistance is relied upon, in practice.

   4.1 The means and methods that improve thermal performance of the building enclosure also improve resistance to transport of externally released CBR agents across the enclosure.

   4.2 Two methods of passive control (i.e., resistance of air and moisture transfer through the building enclosure, and filtration of make-up air) and two methods of active control (i.e., air pressurization control of perimeter zones; and sensing, monitoring and control strategies) are used to impede transportation of CBR agents, and other outdoor air contaminants, across the building enclosure and into occupied spaces.

4.2.1 Passive resistance to the transport of externally released CBR agents involves the integrity of the thermal and moisture transfer characteristics of the building enclosure, the air leakage through the make-up air dampers, and the removal efficiencies of particulate and chemical filtration devices in the make-up air streams.

4.2.2 Active resistance is limited to pressurization control of perimeter zones by the filtered make-up air component of the HVAC sub-system when fenestrations (i.e., windows, doors, natural ventilation ports) are closed, except for the FSL V category that requires detection (i.e., sensing) and control for suspected CBR agents.[12]

4.3 Although the uncertainties are not well-defined or quantified, these methods are being required by ISC-2009[12] and recommended in other standards and guidelines.[13-18]

4.4 These uncertainties are likely to be large as they depend not only on the design but also on the maintenance and operations by the facility staff, and the motivation of the occupants.

5. In addition to resisting transport of contaminants across the building enclosure, CBR protection also requires removal of the externally released agents, which have penetrated the building enclosure, by transporting them to centralized or local filtration systems within the building.

5.1 HVAC interactions for removal of CBR agents that penetrate the building enclosure, and those that are released within the building, are dependent on the air distribution performance of the whole HVAC system, the analysis of which was outside the scope of this phase of the project.

5.2 **The methods of removal of CBR agents within buildings, which are critical for effective and timely CBR protection, should be evaluated and developed in Phase 2.**

Energy Utilization and Production

6. Peak and partial thermal loads of enclosures, with or without blast resistance or CBR protection, do not directly translate to annual energy utilization rates. Therefore, inferential methods were required that consisted of defining energy targets for whole building

energy utilization rates and attributing portions of them to building enclosures.

7. Baseline and benchmark targets for EUI, and corresponding CO_2e values, have been defined on pages C-42 and 43. at minimum/low levels of CBR protection (i.e., baseline = FSL I/II systems 1, 5, 9, and 13 in Table 1, page C-41) for compliance with values that are consistent with federal law and regulations.[1, 12] Expected ranges across climatic zones, and their percentages attributable to the enclosure are summarized in Table 2:

Table 2: Expected ranges across climatic zones of EUI targets and corresponding CO_2e values, and percentages attributable to the opaque and glazed surface areas of the building enclosure at minimum/low level of CBR protection (FSL I/II).

Level of Energy Performance	System (from Table 5-13)	Energy Utilization Intensity (EUI)		Environmental Footprint (CO_2e)	
		kBtu/GSF/yr	% to Enclosure	Lb/GSF/yr	% to Enclosure
Baseline	1	46-70	4-23	9-25	<1-6
P+	5	31-43	1-24	6-15	<1-3
P++	9	22-31	6-30	4-11	<1-3
Future/HP	13	20-29	6-30	3-10	<1-3

7.1 These EUI target values are as much as 5 times lower than the average energy consumption rates in the CBECS database and the validated EUIs from 19 office buildings.[34]

7.2 These EUI target values are presumed to provide for acceptable indoor environmental quality and occupant performance, but evidence exists that this presumption may not be valid.[34]

7.3 **These comparisons reveal the challenge ahead in achieving, validating, and verifying simultaneous energy reduction and CBR protection at the benchmark performance levels (P+, P++, and Future/HP, shown in Table 1 as sub-systems 6, 11 and 16).**

8. Benchmark targets for EUI and corresponding CO_2e values will likely be higher than baseline targets at each incremental increase of CBR protection level: P+ = FSL III, P++ = FSL IV, and Future/HP = FSL V.

8.1 EUI target values and corresponding CO_2e values for these combinations of CBR protection and energy performance have not been estimated in Phase 1. These adjusted values need to be determined in Phase 2.

8.2 **The uncertainties of the outputs for these combinations are high and should be minimized through energy modeling, after the changes in enclosure characteristics, filtration, and control strategies have been included in the model.**

9. The energy production targets and plate area to GSF ratios indicate that the roof-mounted PV options may be applicable for one or two-story buildings, but these options are problematic for taller buildings.

9.1 Although the application of these options provide the capability of offsetting the consumption of fossil fuels to meet part or all of the EUI requirements, they do not reduce the required the capacities or schedules of operations of the HVAC sub-systems.

9.2 The estimated PV-plate area (SF) to GSF ratios needed to offset all of the residual EUIs for a ZNE building are 50-100 percent larger than the ratios for the lighting and plug loads in the P++ category.

9.3 Reliable benchmark performance of the HVAC sub-systems for CBR protection requires the use of redundant energy resources. This requirement is a potential conflict with the concept of ZNE, which requires that, if cost-effective, the residual EUI be met with renewable resources that do not produce greenhouse gases.[1]

Economic Performance

10. Based on the PNNL studies,[25, 26] the first cost of the modeled building at baseline performance (i.e., compliant with ASHRAE 90.1-2004) would be expected to range from $93 – 155/GSF for a 1-4 story office building in the 17 climatic zones. However, experience reveals that actual Class A and monumental buildings have first costs that exceed this range by factors of two or more.

10.1 The estimated incremental first cost of the modeled building in compliance with ASHRAE 50% AEDG[21] at baseline CBR protection, as compared to the building at baseline energy performance in compliance with ASHRAE Standard 90.1-2004,[19] was reported by PNNL[25, 26] to range from $2.37 – 4.22/GSF, which represent 1.5 – 4.5% of the estimated first costs. The incremental first cost of the modeled building for compliance with ZNE requirements has not been estimated in Phase 1.

However, improved enclosure air and moisture integrity, chemical filtration of make-up air or pressurization control for the perimeter zones are likely to increase these incremental cost estimates for improved energy performance.

10.2 These low incremental first costs (e.g., 1.5 – 4.5% of estimated first costs) were rationalized by PNNL to be the result of reduced internal and enclosure loads, and higher energy efficiency of HVAC components including a DOAVS with energy recovery.

10.3 Incremental first costs for increased CBR protection at each level of energy performance have been estimated to range from \$2.50 – 5.00/GSF (e.g., 1.6 – 5.3% of PNNL estimated first costs) for P+ (FSL III); \$6.00 – 11.00/GSF (e.g., 5.4 – 17%) for P++ (FSL IV); and \$7.00 – 13.00/GSF (e.g., 10 – 31%) for Future/HP (FSL V).

10.4 **These incremental first cost estimates need to be validated in Phase 2.**

11. Annual whole-building energy costs were not reported in the PNNL studies[25, 26] but experience reveals that they range from approximately \$1.50/GSF to more than \$5.00/GSF for commercial buildings in the U.S.

11.1 Based on the PNNL studies, annual energy cost savings for a P++ energy performance with baseline CBR protection (FSL I/II) compared to baseline energy and CBR performance may range from \$0.65 – \$0.89/GSF (i.e., 13 – 59% energy cost savings compared to expected range of energy costs) with simple paybacks ranging from 3.3 to 6.2 years for the VAV option, and 5.6 to 11.5 years for the radiant heating and cooling option. Additional energy cost savings are potentially available for the Future/HP energy performance with baseline CBR protection, but have not been estimated in Phase 1.

11.2 Incremental energy costs for increased CBR protection at each level of energy performance have been estimated to range from \$0.50 – \$1.00/GSF/yr for P+ (FSL III); \$0.50 – \$1.00/GSF/yr for P++ (FSL IV); and \$1.00 – \$2.00/GSF/yr for Future/HP (FSL V).

11.3 The incremental energy costs for increased CBR protection that are attributable to the building enclosures are expected to range from \$0.02 – \$0.30/GSF/yr for P+ (FSL III); an additional \$0.02 – \$0.30/GSF/yr for P++ (FSL IV), and an additional \$0.05 – \$0.60/GSF/yr for Future/HP (FSL V).

11.4 **These estimates of incremental energy cost savings need to be validated in Phase 2.**

12. Experience reveals that annual maintenance and operational costs for baseline energy performance and CBR protection may range from $2.00 – 4.00/GSF for commercial buildings in the U.S.

12.1 Incremental maintenance and operational costs for increased CBR protection at each level of energy performance have been estimated to range from $0.50 – $1.00/GSF/yr for P+ (FSL III); $0.50 – $1.00/GSF/yr for P++ (FSL IV); and $2.00 – $3.00/GSF/yr for Future/HP (FSL V).

12.2 The incremental maintenance and operational costs for increased CBR protection that are attributable to the building enclosures were not investigated in Phase 1. Issues include the effects on housekeeping due to open windows (e.g., natural ventilation), building enclosure surfaces, and area of PV sub-systems.

12.3 **These estimates of maintenance and operation costs need to be developed and validated in Phase 2, as they are now based only on the experience of the Mechanical Committee**

13. The definitions of high performance buildings (HBP) and life-cycle cost (LCC) in EISA-2007[1] require the use of an LCC model that optimizes the cost-effectiveness of all of the HPB attributes being considered for a project.

13.1 Energy-based LCC analyses[19-22] provide systematic methods for comparing energy-related alternatives with different streams of costs that assume all other benefits and risks are constant over a defined period. However, an LCC analysis without a risk-benefit analysis is incomplete and may be misleading, as it assumes no difference in costs of risks or values of benefits between options under consideration.

13.2 Risk-benefit methods utilize LCC results to optimize alternatives, based on broad economic foundations.[13, 39-42] These methods account for first costs, energy costs, and other maintenance and operating costs, in conjunction with the economic benefit and risk values for the attributes and sub-attributes.

13.3 Risk-benefit analyses that incorporate LCC provide more comprehensive and accurate evaluations of alternatives to achieve compliance with the set of criteria for the attributes and sub-attributes that pertain to a project during the planning and design phases and should be used in to optimize the cost-effectiveness of all HPB attributes being considered for a project.

14. An LCC model that optimizes the cost-effectiveness of all of the HPB attributes being considered for a project does not apparently exist.

    14.1 **Initially in Phase 2, an LCC program with risk-benefit analysis**[42] **should be interfaced with programs that provide contaminant analysis**[51] **for external and internal releases, and energy analysis**.[52]

    14.2 **Subsequently, the LCC/risk-benefit model should also be interfaced with programs for other sub-attributes (e.g., blast, ballistics, fire, wind, floor) that provide input data to the energy, contamination, and LCC/risk-benefit programs.**

    14.3 **When calibrated, this resultant model should be used in Phase 2 to validate, verify, and/or revise the preliminary predictions.**

Proposed Validation and Verification Procedures

The functional and economic interactions of all of the other attributes and sub-attributes will affect the nexus of CBR protection and EUI. T**o reduce the uncertainties discovered during the development of the preliminary estimates of outcomes in Phase 1, the following two-step process of validation and verification is recommended for Phase 2.**

15. Testing and modeling (Step 1) should be conducted to validate the predicted results for CBR penetration of the building enclosures and the energy and economic impacts of reducing the penetration.

    15.1 In lieu of actual CBR agents, these validation procedures would use normal outdoor air contaminants as surrogates (e.g., water vapor, volatile organic compounds, bioaerosols, and radon) for which references to procedures and quantitative data are available. These procedures are described on pages C-52 and 53.

    15.2 A standardized protocol should be developed for collection and analysis of these data. This protocol should be analogous to those for blast, ballistic, wind and fire protection.

    15.3 Based on the data from laboratory and field testing, and the building and HVAC characteristics, a simulation model (see 14.3) would be used to validate: 1) the predicted distribution effectiveness of the contaminants from the building enclosure to the controlled devices for removal;[31] 2) the whole-building energy utilization (EUI), and corresponding environmental footprint (CO_2e); 3) the percentages of EUI and CO_2e attributable to the enclosure; and 4) the LCC/risk-benefit results.

16. Verification (Step 2) should also be conducted to compare the results from the rationalized predicted performance of site-specific

buildings, being planned or designed, with their actual performances during the construction and operational phases (i.e., cases and controls).

16.1 For technical and financial credibility, the cases in which the data are verified should be determined by an experimental design in which statistically significant results can be expected from a set of case/control buildings.

16.2 A standardized protocol for collection and analysis of the data should be developed to assure valid and reliable results. This protocol should be analogous to those for blast, ballistic, wind and fire protection.

16.3 The verification process should be submitted for peer review and publication.

Proposed Outreach Program

17. **Based on the plans to obtain preliminary predictions, validations and verifications, an outreach/educational program should be developed and implemented in Phase 2 that focuses on scientific, technical, and practical means and methods to improve HPB design and operations for safety, health, security, efficient energy utilization, and cost-effectiveness**.

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Appendices

(Note: Appendices referenced as A-C here and throughout the Detailed Mechanical Analysis are identified as Appendices C.1, C.2, and C.3 in the main HPBDE Project Report.)

Appendix C.1: Spreadsheet on Attributes, Metrics, Benchmarks, Outcomes, 21 May 2011. Attributes Committee and Assignments.

Appendix C.2: Tables 1-6. Identification of Risk Classifications Used in Analysis, 6 December 2010 HPBD-E Committee Meeting, 4 May 2011.

Appendix C.3: Spreadsheets on Calculations for CO_2e, PV Production, and Percentage of Whole-Building Energy Target Attributable to the Building Enclosure, 18 May 2011.

Table C.1-1: Attributes, Metrics, Benchmarks, Outcomes

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	BB
Attributes		**Demands**			**Metric**		**Type/Characteristics**			**Baseline/Benchmarks**				**Performance Outcomes at Threat levels**				**Cost Outcomes**				**Resiliency/Operational Outcomes**			**Overall Outcome**		
Attribute	**Sub-attributes**	**Demands/ Threats**	**Demands/ Threats**	**Demands/ Threats**	**Metric(s)**	**Metric(s)**	**System Type and Characteristics**	**System Type and Characteristics**	**System Type and Characteristics**	**Baseline**	**High Performance Benchmark (P+)**	**High Performance Benchmark (P++)**	**Future/Higher Performance Benchmark**	**Baseline**	**HP Benchmark (P+)**	**HP Benchmark (P++)**	**Future Benchmark**	**Capital Cost**	**O&M Cost**	**Residual/De-Construction Costs**	**Total Cost of Ownership**	**Impact on Continuity of Operations**	**Duration of Lost Operations**	**Relative Loss Factor**	**Relative Importance Score**	**Verification Standards**	**Notes/ Comments/ Questions**
Security	Manmade Hazard: CBR Protection (external release)	**Release Location:** Remote, On-site, Proximate	**Chemical Agent:** "industrialized" or "weaponized" type (thousands of potential agents that can cause various dose-responses, including death)	**Exposure:** Product of Release Strength (i.e., airborne concentration of agent) and duration of release (i.e., time)	**Exposure:** qualitative estimate = low, med, high. For active monitoring and control, quantitative measures are identification, concentration, and time.	**HVAC chemical filter: sorption efficiency (α) and retention time (τ) before breakthrough**	**Size of Building:** small (e.g., < 20,000 GSF) to large (e.g., > 100,000 GSF)	**Fenestration openings:** sizes, locations, methods and schedules of openings	**HVAC System:** Distributed and centralized air handling units (AHU) with various configurations of make-up air intakes; supply, return and exhaust airflow or air exchange rates; supply and distribution ductwork and plenums; and control systems.	Non-customized AHU without chemical filters.	Semi-customized AHU with air-side economizer and low to medium (e.g., 30 - 60%) efficiency chemical (e.g., impregnated active charcoal) filters.	Customized AHU with DOAVS and medium to high (e.g., 60 - 95%) efficiency chemical (e.g., impregnated active charcoal) filters.	Active control systems that close fenestrations, provide SIP, contain and isolate agent, and provided continuous operations, where needed, with customized AHU and DOAVS with medium to high efficiency chemical (e.g., impregnated active charcoal) filters.	**High Vulnerability** with non-customized AHU without chemical filters.	**High to Moderate Vulnerability** with semi-customized AHU, air-side economizer, and low to medium efficiency chemical filters when fenestrations are closed. **High Vulnerability** when fenestrations are open.	**Moderate to Low Vulnerability** with customized AHU and DOAVS, and medium to high efficiency chemical filters, when fenestrations are closed. **High Vulnerability** when fenestrations are open.	Reduced Vulnerability when active control systems are installed.	**Baseline - HP Levels**: Incremental first costs above baseline -- $15 - $95/GSF : P+ = $15 - 35 P++ = $45 - 95 Future = ?	**Baseline - HP Levels:** Incremental Operational and Maintenance Costs of $2 - 10 /GSF/yr: P+ = $2 - 3 P++ = $4 - 10 Future = ?	Residual/De-Construction Costs costs would include cleanup of all chemically contaminated surfaces and replacement of HVAC and control components. This could be a substantial amount with a range of $10 - 200/GSF.	To be calculated by Mark Sands, per Roger Grant	Depending on location, strength and duration of the chemical release, and vulnerability of the facility, the impact on continuity of operations **could range from minor to severe, in a few zones or throughout the whole facility.**	History indicates that chemical contamination may require evacuation of the zones or building for extensive periods and that furnishings and equipment may require replacement.	Score from 0 - 10: This score will range from minor (e.g., 0 - 3) to major (e.g., 8-10) depending on the effectiveness of the system resiliency.	Chemical contamination can range from debilitating to lethal in a zone or throughout the entire facility. Therefore its relative importance is comparable to that for external blasts.	ASHRAE Standard 145.2 - 2010 (gaseous); ASTM D3467 (gaseous); ASHRAE Guide 29-2009	
	Manmade Hazard: CBR Protection (external release)	**Release Location:** Remote, On-site, Proximate	**Chemical Agent:** "industrialized" or "weaponized" type (thousands of potential agents that can cause various dose-responses, including death)	**Exposure:** Product of Release Strength (i.e., airborne concentration of agent) and duration of release (i.e., time)	**Exposure:** qualitative estimate = low, med, high. For active monitoring and control, quantitative measures are identification, concentration, and time.	**Enclosure zone differential air pressure across enclosure, or differential between supply and exhaust airflow rates**	**Size of Building:** small (e.g., < 20,000 GSF) to large (e.g., > 100,000 GSF)	**Fenestration openings:** sizes, locations, methods and schedules of openings	**Pressurization control** provided for distributed and centralized air handling units (AHU) with various configurations of make-up air intakes; supply, return and exhaust airflow or air exchange rates; supply and distribution ductwork and plenums; and control systems.	No pressurization control of non-customized AHU and no chemical filters, with or without open fenestrations.	**Pressurization control** (Δ 10% airflow rate) of semi-customized AHU with air-side economizer and low to medium efficiency chemical filters, and fenestrations are closed. Pressurization will not be controlled when fenestrations are open.	**Pressurization control** (> 0. 05 in w.g. inside to outside pressure differential across all enclosure surfaces) with customized AHU and DOAVS with medium to high efficiency chemical filters, and fenestrations are closed. Pressurization will not be controlled when fenestrations are open.	Active control systems to assure required pressurization across all zones.	**High Vulnerability** with non-customized AHU without chemical filters and no pressurization control.	**Moderate to Low Vulnerability** with semi-customized AHU, air-side economizer, and medium efficiency chemical filters, Δ10% airflow rate control, and all fenestrations closed. High Vulnerability when fenestrations are open.	**Low Vulnerability** with customized AHU and DOAVS, high efficiency chemical filters, and pressurization control across enclosure, when fenestrations are closed. High Vulnerability when fenestrations are open.	Vulnerability is further reduced with active pressurization control strategies.	**Baseline - HP Levels:** Incremental first costs above baseline -- $15 - $95/GSF : P+ = $15 - 35 P++ = $45 - 95 Future = ?	**Baseline - HP Levels:** Incremental Operational and Maintenance Costs of $2 - 10 /GSF/yr: P+ = $2 - 3 P++ = $4 - 10 Future = ?"	Residual/De-Construction Costs costs would include cleanup of all chemically contaminated surfaces and replacement of HVAC and control components. This could be a substantial amount with a range of $10 - 200/GSF.	To be calculated by Mark Sands, per Roger Grant	Depending on location, strength and duration of the chemical release, and vulnerability of the facility, the impact on continuity of operations **could range from minor to severe, in a few zones or throughout the whole facility.**	History indicates that chemical contamination may require evacuation of the zones or building for extensive periods and that furnishings and equipment may require replacement.	Score from 0 - 10: This score will range from minor (e.g., 0 - 3) to major (e.g., 8-10) depending on the effectiveness of the system resiliency.	Chemical contamination can be lethal in a zone or throughout the entire facility. Therefore its relative importance is comparable to that for external blasts.	ASHRAE Std 111-2008 (Measurement, Testing, Adjusting and Balancing of Building Heating, Ventilation and Air-Conditioning Systems); ASTM Standard xxx (pressurization)"	
	Manmade Hazard: CBR Protection (external release)	**Release Location:** Remote, On-site, Proximate	**Biological Agent:** "industrialized" or "weaponized" type (thousands of potential agents that can cause various dose-responses, including death)	**Exposure:** Product of Release Strength (i.e., airborne concentration of agent) and duration of release (i.e., time)	**Exposure:** qualitative estimate = low, med, high. For active monitoring and control, quantitative measures are identification, concentration, and time.	**HVAC particulate filtration: single-pass particulate size removal efficiency (ε) such as Minimum Efficiency Reporting Value (MERV)**	**Size of Building:** small (e.g., < 20,000 GSF) to large (e.g., > 100,000 GSF)	**Fenestration openings:** sizes, locations, methods and schedules of openings	**HVAC System:** Distributed and centralized air handling units (AHU) with various configurations of make-up air intakes; supply, return and exhaust airflow or air exchange rates; supply and distribution ductwork and plenums; and control systems.	Non-customized AHU, installed particulate filters with MERV < 8.	Semi-customized AHU with air-side economizer and 9 > MERV < 13.	Customized AHU with DOAVS and MERV > 13.	Active control systems that close fenestrations, provide SIP, contain and isolate agents, provide continuous operations, where needed, with customized AHU and DOAVS with MERV filters > 13.	**High Vulnerability** with non-customized AHU with particulate MERV filters < 8.	**High to Moderate Vulnerability** with semi-customized AHU, air-side economizer, and 9 > MERV < 13 particulate filters when fenestrations are closed. High Vulnerability when fenestrations are open.	**Moderate to Low Vulnerability** with customized AHU and DOAVS, and MERV filters > 13, when fenestrations are closed. High Vulnerability when fenestrations are open.	Reduced Vulnerability when active control systems are installed.	**Baseline - HP Levels:** Incremental first costs above baseline -- $15 - $95/GSF : P+ = $15 - 35 P++ = $45 - 95 Future = ? "	**Baseline - HP Levels:** Incremental Operational and Maintenance Costs of $2 - 10 /GSF/yr: P+= $2 - 3 P++= $4 - 10 Future = ?"	Residual/De-Construction Costs costs would include cleanup of all microbiologically contaminated surfaces and replacement of HVAC and control components. This could be a substantial amount with a range of $10 - 200/GSF.	To be calculated by Mark Sands, per Roger Grant	Depending on location, strength, and duration of the microbiological release, and vulnerability of the facility, the impact on continuity of operations could range from minor to severe, in a few zones or throughout the whole facility.	History indicates that microbiological contamination may require evacuation of the zones or building for extensive periods and that furnishings and equipment may require replacement.	Score from 0 - 10: This score will range from minor (e.g., 0 - 3) to major (e.g., 8-10) depending on the effectiveness of the system resiliency. I do not understand how this score can be given a priori.	Microbiological contamination can be lethal in a zone or throughout the entire facility. Therefore its relative importance is comparable to that for external blasts.	ASHRAE Standard 52.2-2007 (particulate); ASHRAE Guide 29-2009.	
	Manmade Hazard: CBR Protection (external release)	**Release Location:** Remote, On-site, Proximate	**Biological Agent:** "industrialized" or "weaponized" type (thousands of potential agents that can cause various dose-responses, including death)	**Exposure:** Product of Release Strength (i.e., airborne concentration of agent) and duration of release (i.e., time)	**Exposure:** qualitative estimate = low, med, high. For active monitoring and control, quantitative measures are identification, concentration, and time.	**Enclosure zone differential air pressure across enclosure, or differential between supply and exhaust airflow rates**	**Size of Building:** small (e.g., < 20,000 GSF) to large (e.g., > 100,000 GSF)	**Fenestration openings:** sizes, locations, methods and schedules of openings	**Pressurization control** provided for distributed and centralized air handling units (AHU) with various configurations of make-up air intakes; supply, return and exhaust airflow or air exchange rates; supply and distribution ductwork and plenums; and control systems.	No pressurization control of non-customized AHU with particulate filters MERV < 8, with or without open fenestrations.	Pressurization control (Δ 10% Flowrate) of semi-customized AHU with air-side economizer and 9 > MERV < 13 particulate filters. **Pressurization will not be controlled when fenestrations are open.**	Pressurization control (> 0. 05 in w.g. inside to outside pressure differential across all enclosure surfaces) of customized AHU with DOAVS and MERV > 13 particulate filters. **Pressurization control will not be effective when fenestrations are open.**	Active control systems to assure required pressurization across all zones.	**High Vulnerability** with non-customized AHU, particulate filters with MERV < 8, and no pressurization control.	**Moderate to Low Vulnerability** with semi-customized AHU, air-side economizer, Δ10% airflow rate control, 9 > MERV < 13 particulate filters, and all fenestrations closed. **High Vulnerability** when fenestrations are open.	**Low Vulnerability** with customized AHU and DOAVS, pressurization control across enclosure, MERV > 13 particulate filters, when fenestrations are closed. **High Vulnerability** when fenestrations are open.	Vulnerability is further reduced with active pressurization control strategies.	**Baseline - HP Levels:** Incremental first costs above baseline -- $15 - $95/GSF : HP = $15 - 35 HP+ = $45 - 95 Future = ?	**Baseline - HP Levels:** Incremental Operational and Maintenance Costs of $2 - 10 /GSF/yr: HP = $2 - 3 HP+ = $4 - 10 Future = ?	Residual/De-Construction Costs costs would include cleanup of all microbiologically contaminated surfaces and replacement of HVAC and control components. This could be a substantial amount with a range of $10 - 200/GSF.	To be calculated by Mark Sands, per Roger Grant	Depending on location, strength, and duration of the microbiological release, and vulnerability of the facility, the impact on continuity of operations could range from minor to severe, in a few zones or throughout the whole facility.	History indicates that microbiological contamination may require evacuation of the zones or building for extensive periods and that furnishings and equipment may require replacement.	Score from 0 - 10: This score will range from minor (e.g., 0 - 3) to major (e.g., 8-10) depending on the effectiveness of the system resiliency. I do not understand how this score can be given a priori.	Microbiological contamination can be lethal in a zone or throughout the entire facility. Therefore its relative importance is comparable to that for external blasts.	ASHRAE Std 111-2008 (Measurement, Testing, Adjusting and Balancing of Building Heating, Ventilation and Air-Conditioning Systems); ASTM Standard xxx (pressurization)	

Table C.1-1: Attributes, Metrics, Benchmarks, Outcomes (cont.)

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	BB
Attributes		Demands			Metric		Type/Characteristics			Baseline/Benchmarks				Performance Outcomes at Threat levels				Cost Outcomes				Resiliency/Operational Outcomes			Overall Outcome		
Attribute	Sub-attributes	Demands/ Threats	Demands/ Threats	Demands/ Threats	Metric(s)	Metric(s)	System Type and Characteristics	System Type and Characteristics	System Type and Characteristics	Baseline	High Performance Benchmark (P+)	High Performance Benchmark (P++)	Future/Higher Performance Benchmark	Baseline	HP Benchmark (P+)	HP Benchmark (P++)	Future Benchmark	Capital Cost	O&M Cost	Residual/De-Construction Costs	Total Cost of Ownership	Impact on Continuity of Operations	Duration of Lost Operations	Relative Loss Factor	Relative Importance Score	Verification Standards	Notes/ Comments/ Questions
Security (cont.)	Manmade Hazard: CBR Protection (external release)	Release Location - Remote, On-site, Proximate	Radiological Agent: "industrialized" or "weaponized" type (numerous potential agents that can cause various dose-responses, including death)	Exposure: Product of Release Strength (i.e., airborne concentration of agent) and duration of release (i.e., time)	Exposure: qualitative estimate = low, med, high. For active monitoring and control, quantitative measures are identification, concentration, and time.	**HVAC particulate filter: single-pass particulate size removal efficiency (ε) such as Minimum Efficiency Reporting Value (MERV). (The efficiencies of these filters offer protection only for removal of the fraction of α-particles that is attached to airborne inert or viable particles.)**	Size of Building: small (e.g., < 20,000 GSF) to large (e.g., > 100,000 GSF)	Fenestration openings: sizes, locations, methods and schedules of openings	HVAC System: Distributed and centralized air handling units (AHU) with various configurations of make-up air intakes; supply, return and exhaust airflow or air exchange rates; supply and distribution ductwork and plenums; and control systems.	Non-customized AHU, installed particulate filters with MERV < 8.	Semi-customized AHU with air-side economizer and 9 > MERV < 13.	Customized AHU with DOAVS and MERV > 13.	Active control systems that close fenestrations, provide SIP, contain and isolate agents, provide continuous operations, where needed, with customized AHU and DOAVS with MERV filters > 13.	High Vulnerability with non-customized AHU with particulate MERV filters < 8.	High to Moderate Vulnerability with semi-customized AHU, air-side economizer, and 9 > MERV < 13 particulate filters when fenestrations are closed. High Vulnerabiity when fenestrations are open.	Moderate to Low Vulnerability with customized AHU and DOAVS, and MERV filters > 13, when fenestrations are closed. High Vulnerability when fenestrations are open.	Reduced Vulnerability when active control systems are installed.	"Baseline - HP Levels: Incremental first costs above baseline -- $15 - $95/GSF : HP = $15 - 35 HP+ = $45 - 95 Future = ? "	"Baseline - HP Levels: Incremental Operational and Maintenance Costs of $2 - 10 /GSF/yr: HP = $2 - 3 HP+ = $4 - 9 Future = ?"	Residual/De-Construction Costs costs would include cleanup of all radiologically contaminated surfaces and replacement of HVAC and control components. This could be a substantial amount with a range of $10 - 200/GSF.	To be calcuated by Mark Sands, per Roger Grant	Depending on location, strength, and duration of the radiological release, and vulnerability of the facility, the impact on continuity of operations could range from minor to severe, in a few zones or throughout the whole facility.	History indicates that radiological contamination may require evacuation of the zones or building for extensive periods and that furnishings and equipment may require replacement.	Score from 0 - 10: This score will range from minor (e.g., 0 - 3) to major (e.g., 8-10) depending on the effectiveness of the system resiliency. I do not understand how this score can be given a priori.	Radiological contamination can be lethal in a zone or throughout the entire facility. Therefore its relative importance is comparable to that for external blasts.	"ASME N509-1996 (radiological); ASHRAE Standard 52.2-2007 (particulate); ASHRAE Guide 29-2009 "	
	Manmade Hazard: CBR Protection (external release)	Release Location–Remote, On-site, Proximate	**Radiological Agent:** "industrialized" or "weaponized" type (numerous potential agents that can cause various dose-responses, including death)	**Exposure:** Product of Release Strength (i.e., airborne concentration of agent) and duration of release (i.e., time)	**Exposure:** qualitative estimate = low, med, high. For active monitoring and control, quantitative measures are identification, concentration, and time.	**Enclosure zone differential air pressure across enclosure, or differential between supply and exhaust airflow rates**	**Size of Building:** small (e.g., < 20,000 GSF) to large (e.g., > 100,000 GSF)	Fenestration openings: sizes, locations, methods and schedules of openings	Pressurization control provided for distributed and centralized air handling units (AHU) with various configurations of make-up air intakes; supply, return and exhaust airflow or air exchange rates; supply and distribution ductwork and plenums; and control systems.	No pressurization control of non-customized AHU with particulate filters MERV < 8, with or without open fenestrations.	Pressurization control (Δ 10% Flowrate) of semi-customized AHU with air-side economizer and 9 > MERV < 13 particulate filters. Pressurization will not be controlled when fenestrations are open.	Pressurization control (> 0. 05 in w.g. inside to outside pressure differential across all enclosure surfaces) of customized AHU with DOAVS and MERV > 13 particulate filters. Pressurization control will not be effective if fenestrations are open.	Active control systems to assure required pressurization across all zones.	High Vulnerability with non-customized AHU, particulate filters with MERV < 8, and no pressurization control.	Moderate to Low Vulnerability with semi-customized AHU, air-side economizer, Δ10% airflow rate control, 9 > MERV < 13 particulate filters, and all fenestrations closed. High Vulnerability when fenestrations are open.	Low Vulnerability with customized AHU and DOAVS, pressurization control across enclosure, MERV > 13 particulate filters, when fenestrations are closed. High Vulnerability when fenestrations are open.	Vulnerability is further reduced with active pressurization control strategies.	Baseline - HP Levels: Incremental first costs above baseline -- $15 - $95/GSF : P+ = $15 - 35 P++ = $45 - 95 Future = ?	Baseline - HP Levels: Incremental Operational and Maintenance Costs of $2 - 10 /GSF/yr: P+= $2 - 3 P++ = $4 - 9 Future = ?	Residual/De-Construction Costs costs would include cleanup of all radiologically contaminated surfaces and replacement of HVAC and control components. This could be a substantial amount with a range of $10 - 200/GSF.	To be calculated by Mark Sands, per Roger Grant	Depending on location, strength, and duration of the radiological release, and vulnerability of the facility, the impact on continuity of operations could range from minor to severe, in a few zones or throughout the whole facility.	History indicates that radiological contamination may require evacuation of the zones or building for extensive periods and that furnishings and equipment may require replacement.	Score from 0 - 10: This score will range from minor (e.g., 0 - 3) to major (e.g., 8-10) depending on the effectiveness of the system resiliency. I do not understand how this score can be given a priori.	Radiological contamination can be lethal in a zone or throughout the entire facility. Therefore its relative importance is comparable to that for external blasts.	ASHRAE Std 111-2008 (Measurement, Testing, Adjusting and Balancing of Building Heating, Ventilation and Air-Conditioning Systems); ASTM Standard xxx	
Energy	Enclosure Thermal Load	**Opaque enclosure areas:** Sensible and latent heat gains and losses.	**Opaque enclosure areas:** Sensible and latent thermal loads (i.e., accounting for thermal mass)	**Opaque enclosure areas:** Mass transfer rates of air and water vapor due to infiltration and permeation.	**Btu/hr per ft2** opaque surface area: Sensible and latent gains, losses, and loads.	**Lbs/hr per ft2** opaque surface area: mass transfer rates of air and water vapor.	**Size of Building:** small (e.g., < 20,000 GSF) to large (e.g., > 100,000 GSF)	Types, densities, and properties(e.g., blast resistant and CBR protective characteristics) of surfaces: roof, wall, other; surface to floor area ratios.	Climatic zone; Demographic area; Site and function of building; CBR external pathways; Operational schedule.	Enclosure load in compliance with ASHRAE 90.1-2004 enclosure criteria for climate zone, and building type or function	Reduced annual average sensible and latent enclosure loads through opaque areas for compatibility with goal to achieve annual energy consumption 30% below ASHRAE 90.1-2004 value for climate zone, Blast Protection, CBR Pathways (e.g., infiltration, ingress/egress), and building type or function.	Reduced annual average sensible and latent enclosure loads through opaque areas for compatibility with goal to achieve annual energy consumption 50% below ASHRAE 90.1-2004 value for climate zone, Blast Protection, CBR Pathways (e.g., infiltration, ingress/egress), and building type or function.	Minimized annual average sensible and latent enclosure loads through opaque surfaces for compatibility with Blast Protection, CBR Protection and goal to achieve zero net energy (ZNE) value for the whole building.	Moderate Thermal Vulnerability with minimum compliance with ASHRAE Standard 90.1-2004.	Low Thermal Vulnerability with compliance of opaque enclosures at 30% below ASHRAE Standard 90.1-2004.	Low Thermal Vulnerability with compliance of opaque enclosures at 50% below ASHRAE Standard 90.1-2004.	Low Thermal Vulnerability with compliance of enclosures that are compatible with goal to achieve ZNE.	Baseline - HP Levels: Incremental first costs above baseline -- $15- $95/GSF : P+ = $15 - 35 P++ = $45 - 95 Future = ?	Baseline - HP Levels: Incremental Operational and Maintenance Costs of $2 - 10 /GSF/yr: P+ = $2 - 3 P++ = $4 - 10 Future = ?	Residual/De-Construction Costs costs would include cleanup of all chemically or microbiologically contaminated surfaces or replacement of insulation. This could be a substantial amount with a range of $10 - 50SF.	To be calcuated by Mark Sands, per Roger Grant	Depending on location, strength, and duration of blast or CBR release, and vulnerability of the facility, the impact on continuity of operations could range from minor to severe, in a few zones or throughout the whole facility.	History indicates that failure of the thermal performance of the enclosure may require evacuation of the affected perimeter zones until the enclosure is repaired.	Score from 0 - 10: This score will range from minor (e.g., 0 - 3) to major (e.g., 8-10) depending on the effectiveness of the system resiliency. I do not understand how this score can be given a priori.	Improving the thermal performance of the enclosure over ASHRAE 90.1-2010 will increase thermal comfort, lighting and acoustic responses of occupants, and may have a measurable impact on whole energy consumption. The relative importance of the thermal performance of the enclosure will be suservient to the requirements for safety and security.	ISC - 2009 for FSL I-V; ASHRAE 29-2009 for specified category; NRC-2007 for specified category; ASHRAE 90.1-2004.	Compliance with ASHRAE 90.1-2004 rather than the current 90.1-2010 is for consistency with EISA 2007.
	Enclosure Thermal Load	Glazed enclosure areas: Sensible and latent heat gains and losses through glazed surfaces and open fenestrations.	Glazed enclosure areas: Sensible thermal loads (i.e., accounting for absorption of radiant heat gains and dissipation as conductive and convective loads)	Glazed enclosure areas: Mass transfer rates of air and water vapor through open fenestrations, and by infiltration and permeation through closed glazed areas.	Btu/hr per ft2 glazed surface area: Sensible and latent loads through closed and open glazed areas: sensible and latent loads from infiltration, conductive and convective, and radiant components of the loads.	Lbs/hr per ft2 glazed surface area: mass transfer rates of air and water vapor through glazing and open fenestrations.	Size of Building: small (e.g., < 20,000 GSF) to large (e.g., > 100,000 GSF)	Fenestration openings: sizes, locations, methods and schedules of openings	Climatic zone; Demographic area; Site and function of building; CBR external pathways; Operational schedule.	Enclosure load in compliance with ASHRAE 90.1-2004 enclosure criteria for climate zone, and building type or function	Reduced annual average sensible and latent enclosure loads through glazed areas for compatibility with goal to achieve annual energy consumption 30% below ASHRAE 90.1-2004 value for climate zone, Blast Protection, CBR Pathways (e.g., infiltration, ingress/ egress), and building type or function.	Reduced annual average sensible and latent enclosure loads through glazed areas for compatibility with goal to achieve annual energy consumption50% below ASHRAE 90.1-2004 value for climate zone, Blast Protection, CBR Pathways (e.g., infiltration, ingress/egress), and building type or function.	Minimized annual average sensible and latent enclosure loads through glazed surfaces for compatibility with Blast Protection, CBR Protection and goal to achieve zero net energy (ZNE)values for the whole building.	Moderate Thermal Vulnerability with minimum compliance with ASHRAE Standard 90.1-2004.	Low Thermal Vulnerability with compliance of glazed enclosures at 30% below ASHRAE Standard 90.1-2004 target value.	Low Thermal Vulnerability with compliance of enclosures at 50% below ASHRAE Standard 90.1-2004 target value.	Low Thermal Vulnerability with compliance of enclosures at ZNE.	Baseline - HP Levels: Incremental first costs above baseline -- $15- $95/GSF : P+ = $15 - 35 P++ = $45 - 95 Future = ? "	Baseline - HP Levels: Incremental Operational and Maintenance Costs of $2 - 10 /GSF/yr: P+ = $2 - 3 P+++ = $4 - 10 Future = ?	Residual/De-Construction Costs costs would include cleanup of all CBR contaminated surfaces or replacement of glazing. This could be a substantial amount with a range of $10 - 50/GSF.	To be calcuated by Mark Sands, per Roger Grant	Depending on location, strength, and duration of blast or CBR release, and vulnerability of the facility, the impact on continuity of operations could range from minor to severe, in a few zones or throughout the whole facility.	History indicates that failure of the thermal performance of the enclosure may require evacuation of the affected perimeter zones until the enclosure is repaired.	Score from 0 - 10: This score will range from minor (e.g., 0 - 3) to major (e.g., 8-10) depending on the effectiveness of the system resiliency. I do not understand how this score can be given a priori.	Improving the thermal performance of the enclosure over ASHRAE 90.1-2004 will increase thermal comfort, lighting and acoustic responses of occupants, and may have a measurable impact on whole energy consumption. The relative importance of the thermal performance of the enclosure will be suservient to the requirements for safety and security.	ISC - 2009 for FSL I-V; ASHRAE 29-2009 for specified category; ASHRAE 90.1-2004.	Compliance with ASHRAE 90.1-2004 rather than the current 90.1-2010 is for consistency with EISA 2007.

Table C.1-1: Attributes, Metrics, Benchmarks, Outcomes (cont.)

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	BB
Attributes		**Demands**			**Metric**		**Type/Characteristics**			**Baseline/Benchmarks**				**Performance Outcomes at Threat levels**				**Cost Outcomes**				**Resiliency/Operational Outcomes**			**Overall Outcome**		
Attribute	**Sub-attributes**	**Demands/ Threats**	**Demands/ Threats**	**Demands/ Threats**	**Metric(s)**	**Metric(s)**	**System Type and Characteristics**	**System Type and Characteristics**	**System Type and Characteristics**	**Baseline**	**High Performance Benchmark (P+)**	**High Performance Benchmark (P++)**	**Future/Higher Performance Benchmark**	**Baseline**	**HP Benchmark (P+)**	**HP Benchmark (P++)**	**Future Benchmark**	**Capital Cost**	**O&M Cost**	**Residual/De-Construction Costs**	**Total Cost of Ownership**	**Impact on Continuity of Operations**	**Duration of Lost Operations**	**Relative Loss Factor**	**Relative Importance Score**	**Verification Standards**	**Notes/ Comments/ Questions**
Energy (cont.)	**Whole Building Energy Utilization**	Site Energy: mix, availablility, reliability, and redundancy.	Site Energy: Consumption Costs and Demand Charges.	Site Energy: Percentage of whole building energy consumption required by blast resistant enclosure and CBR protection compared to other end uses (i.e., lighting, ventilation, thermal control, computers and other electrical power)	Btu/GSF/yr: Normalized Annual Energy Consumption: (i.e., Energy Use Intensity or Energy Utilization Index - EUI)	$/GSF/yr: Normalized Annual Energy Cost, with and without Demand Charges.	Size of Building: small (e.g., < 20,000 GSF) to large (e.g., > 100,000 GSF)	All functional energy end-uses are assumed constant except thermal load across the enclosure for blast resistance, and HVAC system requirements for CBR control.	Climatic zone; Demographic area; Site and function of building; CBR external pathways; Operational schedule.	EUI in compliance with baseline annual energy consumption target value per ASHRAE 90.1-2004 (without blast resistance or CBR control).	Reduced EUI to 30% below ASHRAE 90.1-2004 target value, with semi-customized HVAC System with and without blast resistance and CBR protection (i.e., make-up and exhaust ventilation, pressurization, and filtration control).	Reduced EUI to 50% below ASHRAE 90.1-2004 target value, with customized HVAC System with and without blast resistance and CBR protection (i.e., make-up and exhaust ventilation, pressurization, and filtration control).	Minimized annual energy consumption for Blast Protection, with customized HVAC system with and without CBR Protection, and goal to achieve zero net energy value (ZNE) for the whole building	Moderate Energy Vulnerability of the enclosure sub-system with minimum compliance with ASHRAE Standard 90.1-2004 target value during normal conditions.	Moderate to Low Energy Vulnerability of the enclosure sub-system, with and without compliance of blast resistant enclosure, with semi-customized HVAC System, and with and without CPR protection, that is consistent with the target value 30% below ASHRAE Standard 90.1-2004 for the climate zone.	Moderate to Low Energy Vulnerability of the enclosure sub-system, with and without compliance of blast resistant enclosure, with customized HVAC System, and with and without CPR protection, that is consistent with the target value 50% below ASHRAE Standard 90.1-2004 for the climate zone.	Low Energy Vulnerability of the enclosure sub-system, with and without compliance of blast resistant enclosure, with customized HVAC System, and with and without CPR protection, that is consistemt with the target for ZNE performance.	"Baseline - HP Levels: Incremental first costs above baseline -- $15 - $95/GSF : P+ = $15 - 35 P++ = $45 - 95 Future = ? "	"Baseline - HP Levels: Incremental Energy Costs: P+ = ($1.16) (neg) - $0.17 (pos) P++ = ($0.64) (neg) - $0.15 (pos) Future = ?"	Residual/De-Construction Costs costs would include cleanup of all contaminated surfaces and replacement of HVAC and control components. This could be a substantial amount with a range of $10 - 200/GSF.	To be calcuated by Mark Sands, per Roger Grant	Site energy availabilty, reliability and redundancy are crically important to continuity of operations.	Availabilty, reliability and redundancy of site energy resources are crically important to minimize duration of lost operations.	Score from 0 - 10: This score will typically be in the major category (e.g., 8-10), as the building cannot function without energy.	The relative importance score will be high for two reasons: 1) the building cannot function without energy; 2) impact on national energy security may be significant.	ISC - 2009 for FSL I-V; ASHRAE 29-2009 for specified category; ASHRAE 90.1-2004.	Compliance with ASHRAE 90.1-2004 rather than the current 90.1-2010 is for consistency with EISA 2007.
Environment	**Environmental Footprint**	**Site Energy:** Annual whole building energy consumption (EUI) required with and without blast resistant enclosure and CBR protection.	**Site Energy:** Mix of non-renewable site energy resources (e.g., electricity, natural gas, fuel oil) for EUI.	**Environmental Footprint:** Equivalent CO_2 emission (CO_2e) calculated from mix of non-renewable site energy resources and the percentage of EUI that is attributable to blast resistant enclosure and CBR protection.	**Lbs CO_2/kWhr/ GSF** annual electrical consumption. **Lbs CO_2/ therm/ GSF** annual natural gas consumption. **Lbs CO_2/gal/ GSF** annual fuel oil consumption.	**Percentage** of CO_2e, attributable to blast resistant enclosure and CBR protection.	**Size of Building:** small (e.g., < 20,000 GSF) to large (e.g., > 100,000 GSF)	All functional energy end-uses are assumed constant except thermal load across the enclosure for blast resistance, and HVAC system requirements for CBR control.	Climatic zone; e-grid regional zone"	Calculated CO_2e resulting from EUI in compliance with baseline annual energy consumption target value per ASHRAE 90.1-2004, **without blast resistance or CBR control**.	Calculated CO_2e resulting from reduced EUI to 30% below ASHRAE 90.1-2004 target value, with semi-customized HVAC System **with and without blast resistance and CBR protection** (i.e., make-up and exhaust ventilation, pressurization, and filtration control). Calculated incremental reduction in CO_2e by modifying the systems to optimize mix of non-renewable site energy resources, and by adding on-site renewable energy systems.	Calculated CO_2e resulting from reduced EUI to 50% below ASHRAE 90.1-2004 target value, with customized HVAC System **with and without blast resistance and CBR protection** (i.e., make-up and exhaust ventilation, pressurization, and filtration control). Calculated incremental reduction in CO_2e by modifying the systems to optimize mix of non-renewable site energy resources, and by adding on-site renewable energy systems.	Calculated CO_2e resulting from minimized EUI with and without blast protection and with customized HVAC system with and without CBR Protection at ZNE. Calculated incremental reduction in CO_2e by modifying the systems to optimize mix of non-renewable site energy resources, and by adding on-site renewable energy systems.	**Moderate CO_2e Vulnerability** of the enclosure sub-system with minimum compliance with ASHRAE Standard 90.1-2004 target value during normal conditions.	**Moderate to Low CO_2e Vulnerability** of the enclosure sub-system, with and without compliance of blast resistant enclosure, with semi-customized HVAC System, and with and without CPR protection, that is consistent with the target value 30% below ASHRAE Standard 90.1-2004 for the climate zone.	**Moderate to Low CO_2e Vulnerability** of the enclosure sub-system, with and without compliance of blast resistant enclosure, with customized HVAC System, and with and without CPR protection, that is consistent with the target value 50% below ASHRAE Standard 90.1-2004 for the climate zone.		**Baseline - HP Levels**: Incremental first costs for reducing CO_2e, compared to baseline - Without renewable energy systems: $xx- $yy/GSF : P+ = $xx - yy P++ = $xx - yy Future = ? With renewable energy systems: $xx- $yy/GSF : P+ = $xx - yy P++ = $xx - yy Future = ?	**Baseline - HP Levels**: Incremental Operational and Maintenance Costs for reducing CO_2e, compared to baseline - Without renewable energy systems: $x - yy /GSF/yr: P+ = $x - y P++ = $x - yy Future = ? With renewable energy systems: $x - yy /GSF/yr: P+ = $x - y P++ = $x - yy Future = ?	Not applicable		Not applicable.	Not applicable	Score from 0 - 10: Not applicable.	The relative importance score, compared to those for the other sub-attributes, will be moderate to low as the environmental footprint is linked to whole building energy consumption, but is not an independent factor. The impact of the environmental footprint on blast resistant enclosures and CBR protective controls will be minor.	"ASHRAE 90.1-2004, ASHRAE 189-2009, US EPA eGRID2007 Version 1.1, EISA-2007 "	Compliance with ASHRAE 90.1-2004 rather than the current 90.1-2010 is for consistency with EISA 2007.
Sustainability	**Renewable Energy**	**On-Site Energy Production:** Mix of renewable site energy uses (e.g., electricity, water heating, other).	**On-Site Energy Production:** Peak power and annual energy production requirements that can be provided by "cost-effective" (i.e., per EISA 2007) capacities of on-site renewable energy products and systems, which are interfaced with the building enclosure (i.e., solar photovoltaic panels, solar thermal panels, wind turbines that are not free-standing).	**On-Site Energy Production:** Percentages of whole building peak power and annual energy production provided for the building enclosure by "cost-effective" on-site renewable energy products and systems (i.e., solar photovoltaic panels, solar thermal panels, wind turbines) that are interfaced with building enclosure.	**W/GSF or Btu/ hr/GSF** peak electrical power or solar heating production rate. **kWh/GSF or Btu/GSF** annual electrical or solar heating production.	**Percentage** of renewable on-site energy production used to offset peak thermal loads and annual energy consumption with and without blast resistant enclosures and CBR protection.	**Size of Building:** small (e.g., < 20,000 GSF) to large (e.g., > 100,000 GSF)	All functional energy end-uses are assumed constant except thermal load across the enclosure for blast resistance, and HVAC system requirements for CBR control.	Climatic zone; Demographic area; Site and function of building; CBR external pathways, Operational schedule.	Offest of electrical power for lighting and plug loads at EUI for compliance with baseline annual energy consumption target value per ASHRAE 90.1-2004, **without blast resistance or CBR control and with and without non-customized HVAC System**.	Offest of electrical power for lighting and plug loads at reduced EUI of 30% below ASHRAE 90.1-2004 target value, with and without blast resistance, and **with and without semi-customized HVAC System for CBR protection** (i.e., make-up and exhaust ventilation, pressurization, and filtration control).	Offest of electrical power for lighting and plug loads at reduced EUI of 50% below ASHRAE 90.1-2004 target value, **with and without blast resistance, and with and without customized HVAC System for CBR protection** (i.e., make-up and exhaust ventilation, pressurization, and filtration control).	Minimized EUI for Blast Protection and HP+ HVAC system for CBR Protection, by modifying the systems to optimize mix of non-renewable site energy resources, and by achieving ZNE with "cost-effective" on-site renewable energy production.	**Moderate Energy Vulnerability** resulting from non-compliance with the ASHRAE Standard 90.1-2004 target value, with or without solar photovoltaic panels interfaced with the building enclosure.	**Moderate to Low Energy Vulnerability** resulting from failure of the PV sub-system to offset the expected percentage of reduced EUI at 30% below the ASHRAE 90.1-2004 target value, with and without CBR protection.	**Moderate to Low Energy Vulnerability** resulting from failure of the PV sub-system to offset the expected percentage of reduced EUI at 50% below the ASHRAE 90.1-2004 target value, with and without CBR protection.	**Moderate Energy Vulnerability** resulting from failure of the PV sub-system to offset the residual EUI required to achieve ZNE, with and without CBR protection.	**Baseline - HP Levels:** Incremental first costs for on-site renewable energy systems, above baseline (including mechanical, electrical, architectural and structural costs)-- $11,000/kW-$24,000/kW : P+ = $11,000/ kW P++ = $24,000/ kW Future = ?	**Baseline - HP Levels:** Incremental O&M costs for on-site renewable energy systems, compared to baseline: P+ = ($x.xx) (neg) - $y.yy (pos) P++ = ($x.xx) (neg) - $y.yy (pos) Future = ? Range of useful energy: 0.7 to 1.1 kWh/day-m2 of plate. Cost of power: $10 - 150 per kWh. Potential cost savings of electrical power: $7 to $150/ day-m2 of plate.	Residual/De-Construction Costs costs would include cleanup of all contaminated surfaces, and HVAC and control components. This could be a substantial amount with a range of $10 - 200/GSF.	To be calculated by Mark Sands, per Roger Grant. Note: the "cost-effectiveness" determination by the owner will dictate the capacity of the renewable energy system.	Site energy availability, reliability and redundancy of renewable and non-renewables resources are critically important to continuity of operations. The incremental impact of on-site renewable energy products and systems that are interfaced with the building enclosure could have either positive or negative impact, dependent upon the resiliency of the renewable energy systems during response and recovery times.	Availability, reliability and redundancy of site energy are critically important to minimize duration of lost operations. On-site renewable energy resources could incrementally reduce duration of lost operations, if they are resilient.	Score from 0 - 10: This score will typically be in the major category (e.g., 8-10), as the building cannot function without energy.	The relative importance score will be high for two reasons: 1) the building cannot function without energy; 2) impact on national energy security may be significant.	ASHRAE 90.1-2010, ASHRAE 189-2009, EISA 2007"	Compliance with ASHRAE 90.1-2004 rather than the current 90.1-2010 is for consistency with EISA 2007.

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Appendix C.2 Identification of Risk Classifications Used in Analysis

Table C.2-1: Identification of Risk Classifications Used in Analysis

ISC 2009[12]: **Facility Security Level (FSL)** **Level of Risk (LOR)** **Level of Protection (LOP)** Physical Security Criteria for Federal Facilities	**I** **Minimum** **Minimum** (Consequences not specified)	**II** **Low** **Low** (Consequences not specified)	**III** **Moderate** **Moderate** (Consequences not specified)	**IV** **High** **High** (Consequences not specified)	**V** **Very High** **Very High** (Consequences not specified)
ASHRAE 29-2009[13]: **Risk Category** Guidelines for the Risk Management of Public Health and Safety in Buildings	**Negligible** No System Performance Effect; no Impact on Health/Safety	**Minor** Some Disruption in System Performance; no Impact on Health/Safety, but Some Discomfort Likely	**Moderate** Significant Disruption in System Performance or some Impact on Health/Safety	**Serious** Major Disruption in System Performance or Significant Impact on Health/Safety	**Critical** Failure of System Performance or Major Impact on Health/Safety
NRC 2007[14]: **Level of Protection** Protecting Building Occupants and Operations from Biological and Chemical Airborne Threats	**LP-1** **Low-Level Passive Protection** (i.e., no active sensing for threat agents): "Well-maintained building provides a healthy environment for occupants and operations."	**LP-2** **High-Level Passive Protection:** "Provides protection by further limiting exposure to intentionally released threat agents." Protection is similar to MilStd Class I Collective Protection (USACE, 1999).	**P-3** **Low-Level Active Protection:** "A 'detect-to-treat' option that would allow identification of a threat agent in time for treatment."	**LP-4** **High-Level Active Protection:** Allows "detection and identification early enough to treat the exposed victims and to make operational responses that might minimize the impact of the threat agent by preventing or limiting exposure."	

Table C.2-2: Response Functions for ISC 2009 Facility Security Level I (FSL-I).

- Corresponding ISC Level of Risk (LOR) and Level of Protection (LOP): **Minimum**
- Corresponding ASHRAE 29-2009 Risk Category: **Negligible**

Attribute	Enclosure Interactions		HVAC System Interactions			Cost Estimates
	Thermal Transmission (Blast Resistance)	CBR Protection (External Releases)	Pressurization Control	Filtration Control	Sensing/Monitoring and Control	
Metric	Thermal Loads (Btu/hr) through building enclosure and penetrations	Contaminant Loads (mass/hr)) through building enclosure and penetrations	Airflow Rate (cfm) or pressure (in. H2O) difference	Contaminant Removal Rate (mass/hr)	Safety/Security Energy Consumption (Btu/GSF/yr) Sustainability	First Costs ($/GSF) Operational and Maint. Costs ($/GSF/yr)
Value	$Q_t = U_o A_o \Delta T_{i\text{-}o}$	$Q_c = M_o A_o \Delta P_{i\text{-}o}$	$\Delta P_{s\text{-}r}$ or $\Delta V_{s\text{-}r}$	$E = V \sum \varepsilon_i c_i$		
Baseline	No special ISC requirements.	Provide emergency shut-down, SIP, and evacuation procedures No other special ISC requirements.	No special ISC requirements	No special ISC requirements	No special ISC requirements	First Costs: $30 – 120/GSF depending on building type, zonal functions, climate zones and other factors Operational and Maintenance Costs: $2 – 5/GSF/yr
	Design sensible and latent loads (Q_t) based on compliance with ASHRAE 90.1-2004 requirements for building type and climate zone	Peak loads (Q_c) of known contaminants based on compliance with PBS P100-2010 enclosure tightness criteria of 0.3 cfm/sf at 0.3 in. wg (75 Pa), with windows and doors closed	$\Delta P_{s\text{-}r}$ or $\Delta V_{s\text{-}r}$ = 10%, accounting for natural and mechanical ventilation, exhaust systems, and enclosure tightness, per PBS P 100-2010 Outside air for ventilation in accordance with 62.1-2010 for building type and zonal functions	> MERV 13 for all AHUs and > MERV 10 for terminal units (e.g., FCUs. FPVAVs) per PBS P100-2010 and ASHRAE 29-2009 Ventilation rates in accordance with ASHRAE 62.1-2010 (Appendix D) or PBS P 100-2010 for filter efficiency, building type and zonal functions ADPI > 80% per PBS P100-2010	Interface between BAS, fire/smoke, elevator safety, lighting, and security control systems in accordance with life-safety codes per PBS P100-2010 Control strategies and oversight monitoring to manage indoor environmental quality (e.g., thermal, lighting, acoustics, and contaminant exposures), sustainability goals, and energy consumption during normal conditions, in accordance with OPR	
Benchmarks	Minimized annual average sensible and latent enclosure loads (Q_t ave) to comply with whole-building energy targets: 30% below ASHRAE 90.1-2004 (P+); 50% below ASHRAE 90.1-2004 (P++); or Other HP Goals per OPR.	Minimized peak loads from known contaminants (Q_c) based on enclosure tightness in accordance with draft ASTM Standard of 0.1 cfm/sf at 0.3 in. wg (75Pa) $\Delta P_{i\text{-}o}$ with windows and doors closed (in draft form – See note from Dan Lemieux)	Enhanced pressurization control for interzonal differences: $\Delta P_{i\text{-}o}$ and $\Delta P_{i\text{-}j}$ for normal conditions in accordance with OPR	Enhanced filtration control for gaseous contaminants (e.g., use adsorption filtration) per ASHRAE 29-2009 and NRC-2007 Enhanced air distribution control and minimized time for removal (i.e., time constant) of externally and internally released contaminants by eliminating supply and return air plenums and minimizing lengths of supply air and return air ductwork per ASHRAE 29-2009 and NRC 2007	Enhanced control strategies to optimize the goals of the eight WBDG HPB attributes (i.e., see www.wbdg.org): aesthetics, cost-effective, functional/operational, historic preservation, productive, safe and secure, and sustainable (i.e., including six parameters, one of which is energy use) during normal conditions	First Costs: TBD ($/GSF) Operational and Maintenance Costs: TBD ($/GSF/yr)

Attribute	Enclosure Interactions		HVAC System Interactions			Cost Estimates
	Thermal Transmission (Blast Resistance)	CBR Protection (External Releases)	Pressurization Control	Filtration Control	Sensing/Monitoring and Control	
Comments: (Related Forcing Functions and Manipulated Variables)	Minimum or negligible blast risk (ISC, ASHRAE 29-2009) Negligible risk from natural, accidental or intentional events (ASHRAE 29-2009) Normal design weather/climate conditions Normal site conditions Normal building type, size and function Normal intrinsic thermal properties of enclosure Normal floor/wall area ratios (e.g., F/W = unlimited) percentage of glazing (e.g., 40% of wall area per ASHRAE 90.1-2004)	Minimum or negligible risk of external CBR release risk (ISC, ASHRAE 29-2009) Negligible risk from natural, accidental or intentional events (ASHRAE 29-2009) Normal design weather/climate and outdoor contaminant conditions Normal site conditions Normal building type, size and function Normal intrinsic moisture and contaminant resistant properties of enclosure Normal design of operable windows and natural ventilation	Zone functions, configurations and isolation Type and size of HVAC System, including exhaust air system Location of Make-up-air intake(s) Location and types of windows and other natural ventilation devices Ductwork and plenum configuration Location of supply air diffusers and return air grilles (i.e., room air exchange effectiveness and response time)	Zone contaminant loads by type (i.e., particulate, gaseous, vapor) Type and size of HVAC System, including exhaust air system Type, efficiency and location of filtration devices Location of Make-up-air intake(s) Ductwork and plenum configuration Location of supply air diffusers and return air grilles (i.e., room contaminant removal effectiveness and response time)	Types of sensors and control loops in BAS Accuracy and response times of sensors and control loops Types of control strategies provided by BAS Types of interfaces between BAS and other supervisory systems (e.g., fire/life-safety, security)	
NRC 2007 Classification	LP-1				LP-3	

Table C.2-3: Response Functions for ISC 2009 Facility Security Level II (FSL-II).

- Corresponding ISC Level of Risk (LOR) and Level of Protection: **Low**
- Corresponding ASHRAE 29-2009 Risk Category: **Minor**

	Enclosure Interactions		HVAC System Interactions			
Attribute	Thermal Transmission (Blast Resistance)	CBR Protection (External Releases)	Pressurization Control	Filtration Control	Sensing/Monitoring and Control	Cost Estimates
Metric	Thermal Loads (Btu/hr) through building enclosure and penetrations	Contaminant Loads (mass/hr) through building enclosure and penetrations	Airflow Rate (cfm) or pressure (in. H2O) difference	Contaminant Removal Rate (mass/hr)	Safety/Security Energy Consumption (Btu/GSF/yr) Sustainability	First Costs ($/GSF) Operational and Maintenance Costs ($/GSF/yr)
Value	$Q_t = U_o A_o \Delta T_{i-o}$	$Q_c = M_o A_o \Delta P_{i-o}$	ΔP_{s-r} or ΔV_{s-r}	$E = V \sum \varepsilon_i c_i$		
Baseline	No special ISC requirements.	Provide emergency shut-down, SIP, and evacuation procedures Secure accessible air intake grilles from tampering or removal No other special ISC requirements.	Develop written procedures for the emergency shut-down or exhaust of air handling systems No other special ISC requirements.	No special ISC requirements	Protect the system controls from unauthorized access No other special ISC requirements	Incremental First Costs to FSL I: $10 - 50 /GSF depending on sensing and control strategies, building type, zonal functions, climate zones and other factors Incremental Operational and Maintenance Costs to FSL I: $2 – 4 /GSF/yr depending on building type, zonal functions, climate zones and other factors
	Maintain overall heat transfer coefficient (Uo) at FSL I value by modifying enclosure to compensate for added structural support (e.g., thermal bridges) Achieve same Qt and energy target as for FSL I during normal conditions	Maintain overall moisture and contaminant transfer coefficients (Mo) at FSL I values by modifying the enclosure to compensate for additional types and intensities of external CBR releases as determined by the threat analysis Use tight shut-off dampers for Make-up Air Intakes and Exhaust Air Discharges Achieve same Qc as for FSL I during normal and extraordinary conditions based on compliance with PBS P100-2010 enclosure tightness criteria of 0.3 cfm/sf at 0.3 in. wg (75 Pa) with windows and doors closed	Increased number of perimeter and interior zones in accordance with ASHRAE 29-2009 and OPR ΔPs-r or ΔVs-r = 10%, accounting for interzonal pressurization requirements per ASHRAE 29-2009; exhaust systems and enclosure tightness, per PBS P 100-2010; and outside air for ventilation in accordance with ASHRAE 62.1-2010 for building type and zonal functions	> MERV 13 for all AHUs and MERV 10 for terminal units (e.g., FCUs, FPVAVs) per PBS P100-2010 and ASHRAE 29-2009 In areas specified by OPR, provide local air washers with laminar airflow and local (high efficiency) filtration of recirculation air per NRC 2007 Provide ventilation rates in accordance with ASHRAE 62.1-2010 (Appendix D) or PBS P 100-2010 for filter efficiency, building type and zonal functions Use filtered Dedicated Outside Air Systems (DOAVS) per PBS P100-2010, NRC 2007 and ASHRAE 29-2009 Eliminate supply air plenums (i.e., UFAD) and minimize return air plenums per NRC 2007 ADPI > 80% per P100-2010 Minimized use of supply air and return air plenums (i.e., use ductwork) to minimize cross-contamination per NRC-2007 and ASHRAE 29-2009	Interface between BAS, fire/smoke, elevator safety, lighting, and security control systems in accordance with life-safety codes per PBS P100-2010 Control strategies and oversight monitoring to manage indoor environmental quality (e.g., thermal, lighting, acoustics, and contaminant exposures), sustainability goals, and energy consumption during normal conditions, in accordance with OPR	

Attribute	Enclosure Interactions		HVAC System Interactions			Cost Estimates
	Thermal Transmission (Blast Resistance)	CBR Protection (External Releases)	Pressurization Control	Filtration Control	Sensing/Monitoring and Control	
Benchmarks	Same as for FSL I: Minimized annual average sensible and latent enclosure loads (Qt ave) to comply with whole-building energy targets: 30% below ASHRAE 90.1-2004 (P+); 50% below ASHRAE 90.1-2004 (P++); or Other HP Goals per OPR.	Minimized peak loads (Qc) from additional types and intensities of externally released CBR contaminants, as determined by the threat analysis and based on enclosure tightness in accordance with draft ASTM Standard of 0.1 cfm/sf at 0.3 in. wg (75Pa) ΔPi-o with windows and doors closed	Enhanced pressurization sensing and control for interzonal differences: ΔPi-o and ΔPi-j for normal and extraordinary conditions in accordance with OPR Use Dedicated Outside Air Ventilation Systems (DOAVS), eliminate use air-side economizers, and increase use filtration per PBS P100-2010, ASHRAE 29-2009, and NRC 2007 Eliminate supply air and return air plenums (i.e., use ductwork) per NRC 2007 and ASHRAE 29-2009	Enhanced filtration control for gaseous contaminants (e.g., use adsorption filtration) per NRC-2007 and ASHRAE 29-2009 Enhanced air distribution control and minimize time for removal (i.e., time constant) of externally and internally released contaminants by minimizing lengths of supply air and return air ductwork per ASHRAE 29-2009 and NRC 2007	Sensors and feedbackward or feedforeword control for preparation and response to threats of known CBR agents per NRC-2007 Enhanced control strategies for detection, identification and responses to external (and internal) releases of CBR agents per NRC-2007 Enhanced control strategies to optimize the goals of the eight HPB attributes (i.e., see www.wbdg.org): aesthetics, cost-effective, functional/operational, historic preservation, productive, safe and secure, and sustainable (i.e., including six parameters, one of which is energy use) during normal and extraordinary conditions	Incremental First Costs to FSL I: TBD ($/GSF) Incremental Operational and Maintenance Costs to FSL I: TBD ($/GSF/yr)
Comments: (Related Forcing Functions and Manipulated Variables)	Low/Minor blast risk (ISC, ASHRAE 29-2009) Minor risk from natural, accidental or intentional events (ASHRAE 29-2009) Normal design weather/climate conditions At-risk site conditions (ISC, ASHRAE 29-2009) At-risk building type, size and function Modified intrinsic thermal properties of enclosure Increased floor/wall area ratios from ISC FSL I (see Table 2r) Reduced percentage of glazing from ISC FSL I (see Table 2r)	Low/Minor risk of external CBR release risk (ISC, ASHRAE 29-2009) Minor risk from natural, accidental or intentional events, including internal CBR releases (ASHRAE 29-2009) Normal design weather/climate conditions Increased threat of types, intensities and durations of outdoor contaminant releases At-risk site conditions for natural, accidental, or intentional extraordinary events (ISC, ASHRAE 29-2009) Modified building type, size and function Modified intrinsic moisture and contaminant resistant properties of enclosure Modified design of operable windows and natural ventilation systems	Zone functions, configurations and isolation Type and size of HVAC System, including exhaust air system Location of Make-up-air intake(s) Location and types of seals for doors, windows, dampers, and interzonal penetrations Ductwork and plenum configuration Location of supply air diffusers and return air grilles (i.e., room air exchange effectiveness and response time)	Zone contaminant loads by type (i.e., particulate, gaseous, vapor) Type and size of HVAC System, including exhaust air system Type, efficiency and location of filtration devices Location of Make-up-air intake(s) Ductwork and plenum configuration Location of supply air diffusers and return air grilles (i.e., room contaminant removal effectiveness and response time)	Types of sensors and control loops in BAS Accuracy and response times of sensors and control loops Types of control strategies provided by BAS Types of interfaces between BAS and other supervisory systems (e.g., fire/life-safety, security)	
NRC 2007 Classification	LP-1				LP-3	

Table C.2-4: Response Functions for ISC 2009 Facility Security Level III (FSL-III).

- Corresponding ISC Level of Risk (LOR) and Level of Protection: Moderate
- ASHRAE 29-2009 Risk Category: Moderate

Attribute	Enclosure Interactions		HVAC System Interactions			Cost Estimates
	Thermal Transmission (Blast Resistance)	CBR Protection (External Releases)	Pressurization Control	Filtration Control	Sensing/Monitoring and Control	
Metric	Thermal Loads (Btu/hr) through building enclosure and penetrations	Contaminant Loads (mass/hr)) through building enclosure and penetrations	Airflow Rate (cfm) or pressure (in. H2O) difference	Contaminant Removal Rate (mass/hr)	Safety/Security Energy Consumption (Btu/GSF/yr) Sustainability	First Costs ($/GSF) Operational and Maintenance Costs ($/GSF/yr)
Value	$Q_t = U_o A_o \Delta T_{i\text{-}o}$	$Q_c = M_o A_o \Delta P_{i\text{-}o}$	$\Delta P_{s\text{-}r}$ or $\Delta V_{s\text{-}r}$	$E = V \sum \varepsilon_i c_i$		
Baseline	No special ISC requirements.	Provide emergency shut-down, SIP, and evacuation procedures Secure accessible air intake grilles with fencing Monitor air intake grilles with CCTV monitoring or guard patrols No other special ISC requirements	Develop written procedures for the emergency shut-down or exhaust of air handling systems Provide separate isolated HVAC systems in lobbies, loading docks, mail rooms, and other locations susceptible to CBR attack that are isolated from other building areas No other special ISC requirements.	Use Minimum Efficiency Reporting Value (MERV) 10 particulate filter on all exterior AHUs for biological filtration of general building Use MERV 13 particulate filter on all AHUs in mailrooms and lobbies for biological filtration No other special ISC requirements	Protect the system controls from unauthorized access Install an emergency shut-off and exhaust system for air handlers Control movement of elevators and close applicable doors and dampers to seal building No other special ISC requirements	Incremental First Costs to FSL II: $10 - 50 /GSF depending on sensing and control strategies, building type, zonal functions, climate zones and other factors Incremental Operational and Maintenance Costs to FSL II: $2 – 6 /GSF/yr depending on building type, zonal functions, climate zones and other factors
	Maintain overall heat transfer coefficient (U_o) at FSL I values by modifying enclosure to compensate for added structural support (e.g., thermal bridges) Achieve same Q_t and energy target as for FSL I during normal conditions	Maintain overall moisture and contaminant transfer coefficients (Mo) at FSL I values by modifying the enclosure to compensate for additional types and intensities of external CBR releases as determined by the threat analysis Use tight shut-off dampers for Make-up Air Intakes and Exhaust Air Discharges Outside air intakes to be located on roof or high wall (i.e., high rise building) - > 30 ft above grade per ASHRAE 29-2009 Achieve same Qc as for FSL I during normal and extraordinary conditions based on compliance with PBS P100-2010 enclosure tightness criteria of 0.3 cfm/sf at 0.3 in. wg (75 Pa) with windows and doors closed	Increased number of perimeter and interior zones in accordance with ASHRAE 29-2009 and OPR Separate air distribution system for each pressurization zone, including public areas, per ASHRAE 29-2009 AHUs on each floor (i.e., floor-by-floor) per ASHRAE 29-2009 Ductwork routed to avoid unauthorized access per ASHRAE 29-2009 ΔPs-r or ΔVs-r = 10%, accounting for interzonal pressurization requirements per ASHRAE 29-2009; exhaust systems and building tightness, per PBS P 100-2010; and outside air for ventilation in accordance with ASHRAE 62.1-2010 for building type and zonal functions	> MERV 13 for all AHUs and > MERV 10 for terminal units (e.g., FCUs) per PBS P100-2010 and ASHRAE 29-2009 > MERV 17 for recirculation AHUs in each pressurization zone per ASHRAE 29-2009 In areas specified by OPR, provide local air washers with laminar airflow and local (high efficiency) filtration of recirculation air per NRC 2007 Ventilation rates in accordance with ASHRAE 62.1-2010 (Appendix D) or PBS P 100-2010 for filter efficiency, building type and zonal functions Use filtered Dedicated Outside Air Systems (DOAVS)) per PBS P100-2010, NRC 2007 and ASHRAE 29-2009 Eliminate supply air plenums (i.e., UFAD) and minimize return air plenums to minimize cross-contamination per NRC 2007 ADPI > 80% per P100-2010	Interface between BAS, fire/smoke, elevator safety, lighting, and security control systems in accordance with life-safety codes per PBS P100-2010 Control strategies for system shut-downs without exacerbating occupant exposure to externally or internally released CBR agents per ASHRAE 29-2009 Control strategies and oversight monitoring to manage indoor environmental quality (e.g., thermal, lighting, acoustics, and contaminant exposures), sustainability goals, and energy consumption in accordance with OPR	

Attribute	Enclosure Interactions: Thermal Transmission (Blast Resistance)	Enclosure Interactions: CBR Protection (External Releases)	HVAC System Interactions: Pressurization Control	HVAC System Interactions: Filtration Control	HVAC System Interactions: Sensing/Monitoring and Control	Cost Estimates
Benchmarks	Same as for FSL I: Minimized annual average sensible and latent enclosure loads ($Q_{t\ ave}$) to comply with whole-building energy targets: 30% below ASHRAE 90.1-2004 (P+); 50% below ASHRAE 90.1-2004 (P++); or Other HP Goals per OPR.	Minimized peak loads (Q_c) from additional types and intensities of externally released CBR contaminants, as determined by the threat analysis and based on enclosure tightness in accordance with draft ASTM Standard of 0.1 cfm/sf at 0.3 in. wg (75Pa) $\Delta P_{i\text{-}o}$ with windows and doors closed	Enhanced pressurization sensing and control for interzonal differences: $\Delta P_{i\text{-}o}$ and $\Delta P_{i\text{-}j}$ for normal and extraordinary conditions in accordance with OPR Use Dedicated Outside Air Ventilation Systems (DOAVS), eliminate use air-side economizers, and increase use filtration to enhance pressurization control per PBS P100-2010, ASHRAE 29-2009, and NRC 2007 Eliminate supply air and return air plenums (i.e., use ductwork) to enhance pressurization control per NRC 2007 and ASHRAE 29-2009	Enhanced filtration control for gaseous contaminants (e.g., use adsorption filtration) Enhanced air distribution control and minimize time for removal (i.e., time constants) of externally or internally released particulate and gaseous contaminants by minimizing lengths of supply air and return air ductwork	Sensors and feedbackward or feedforeword control for preparation and response to threats of known CBR agents Enhanced control strategies for detection, identification and responses to external (and internal) releases of CBR agents Enhanced control strategies to optimize the goals of the eight HPB attributes (i.e., see WBDG): aesthetics, cost-effective, functional/operational, historic preservation, productive, safe and secure, and sustainable (i.e., including six parameters, one of which is energy use) during normal and extraordinary conditions	<u>Incremental First Costs to FSL II</u>: TBD ($/GSF) <u>Incremental Operational and Maintenance Costs to FSL II</u>: TBD ($/GSF/yr)
Comments: (Related Forcing Functions and Manipulated Variables)	Moderate blast risk (ISC, ASHRAE 29-2009) Moderate risk from natural, accidental or intentional events (ASHRAE 29-2009) Normal design weather/climate conditions At-risk site conditions (ISC, ASHRAE 29-2009) At-risk building type, size and function Increased blast resistant enclosure compared to FSL II Modified intrinsic thermal properties of enclosure Increased floor/wall area ratios from ISC FSL II (see Tables 2 and 3) Reduced percentage of glazing from ISC FSL II (see Tables 2 and 3)	Moderate risk of external CBR release (ISC, ASHRAE 29-2009) Moderate risk from natural, accidental or intentional events, including internal CBR releases (ASHRAE 29-2009) Normal design weather/climate conditions Increased threat of types, intensities and durations of outdoor contaminant releases compared to FSL II At-risk site conditions for natural, accidental, or intentional extraordinary events (ISC, ASHRAE 29-2009) Modified building type, size and function Modified intrinsic moisture and contaminant resistant properties of enclosure Modified design of operable windows and natural ventilation systems	Zone functions, configurations and isolation Type and size of HVAC System, including exhaust air system Location of Make-up-air intake(s) Location and types of seals for doors, windows, dampers, and interzonal penetrations Ductwork and plenum configuration Location of supply air diffusers and return air grilles (i.e., room air exchange effectiveness and response time)	Zone contaminant loads by type (i.e., particulate, gaseous, vapor) Type and size of HVAC System, including exhaust air system Type, efficiency and location of filtration devices Location of Make-up-air intake(s) Ductwork and plenum configuration Location of supply air diffusers and return air grilles (i.e., room contaminant removal effectiveness and response time)	Types of sensors and control loops in BAS Accuracy and response times of sensors and control loops Types of control strategies provided by BAS Types of interfaces between BAS and other supervisory systems (e.g., fire/life-safety, security)	
NRC 2007 Classification	LP-2				LP-3	

Table C.2-5: Response Functions for ISC 2009 Facility Security Level IV (FSL-IV).

- Corresponding ISC Level of Risk (LOR) and Level of Protection: **High**
- Corresponding ASHRAE 29-2009 Risk Category: **Serious**

Attribute	Enclosure Interactions		HVAC System Interactions			Cost Estimates
	Thermal Transmission (Blast Resistance)	CBR Protection (External Releases)	Pressurization Control	Filtration Control	Sensing/Monitoring and Control	
Metric	Thermal Loads (Btu/hr) through building enclosure and penetrations	Contaminant Loads (mass/hr) through building enclosure and penetrations	Airflow Rate (cfm) or pressure (in. H2O) difference	Contaminant Removal Rate (mass/hr)	Safety/Security Energy Consumption (Btu/GSF/yr) Sustainability	First Costs ($/GSF) Operational and Maintenance Costs ($/GSF/yr)
Value	$Q_t = U_o A_o \Delta T_{i\text{-}o}$	$Q_c = M_o A_o \Delta P_{i\text{-}o}$	$\Delta P_{s\text{-}r}$ or $\Delta V_{s\text{-}r}$	$E = V \sum \varepsilon_i c_i$		
Baseline	No special ISC requirements.	Provide emergency shut-down, SIP, and evacuation procedures Place air intakes on rooftop or on wall at least 30 feet or 3 stories above grade Ensure that the enclosure of the isolated loading docks and mail room are full-height construction and are sealed to the floor, roof or ceiling above No other special ISC requirements	Provide separate isolated HVAC systems in lobbies, loading docks, mail rooms, and other locations susceptible to CBR attack that are isolated from other building areas No other special ISC requirements.	Use Minimum Efficiency Reporting Value (MERV) 13 particulate filter on all AHUs, including the supply air stream for recirculating AHUs in mailrooms and lobbies, for biological filtration of general building No other special ISC requirements	Provide Intrusion Detection System (IDS) coverage of ventilation equipment and control rooms Install a one-step shut-off and exhaust system for air handlers Control movement of elevators and close applicable doors and dampers to seal building Provide an emergency response module to the building's energy management system (i.e., BAS) to switch the system to a prescribed emergency response mode No other special ISC requirements	Incremental First Costs to FSL III: $20 - 80/GSF depending on sensing and control strategies, building type, zonal functions, climate zones and other factors Incremental Operational and Maintenance Costs to FSL III: $2 – 6 /GSF/yr depending on building type, zonal functions, climate zones and other factors
	Maintain overall heat transfer coefficient (Uo) at FSL I values by modifying enclosure to compensate for added structural support (e.g., thermal bridges) Achieve same Qt and energy target as for FSL I during normal conditions	Maintain overall moisture and contaminant transfer coefficients (Mo) at FSL I values by modifying the enclosure to compensate for additional types and intensities of external CBR releases as determined by the threat analysis Use tight shut-off dampers for Make-up Air Intakes and Exhaust Air Discharges Outside air intakes to be located on roof or high wall (i.e., high rise building) - > 30 ft above grade per ASHRAE 29-2009 Achieve same Qc as for FSL I during normal and extraordinary conditions based on compliance with PBS P100-2010 enclosure tightness criteria of 0.1 cfm/sf at 0.3 in. wg (75 Pa) with windows and doors closed	Increased number of perimeter and interior zones in accordance with ASHRAE 29-2009 and OPR Separate air distribution system for each pressurization zone, including public areas, per ASHRAE 29-2009 AHUs on each floor (i.e., floor-by-floor) per ASHRAE 29-2009 Ductwork routed to avoid unauthorized access per ASHRAE 29-2009 ΔPs-r or ΔVs-r = 10%, accounting for interzonal pressurization requirements per ASHRAE 29-2009; exhaust systems and building tightness, per PBS P 100-2010; and outside air for ventilation in accordance with ASHRAE 62.1-2010 for building type and zonal functions	> MERV 13 for all AHUs and > MERV 10 for terminal units (e.g., FCUs) per PBS P100-2010 and ASHRAE 29-2009 > MERV 17 or higher for recirculation AHUs in each pressurization zone per ASHRAE 29-2009 In areas specified by OPR, provide local air washers with laminar airflow and local (high efficiency) filtration of recirculation air per NRC 2007 Ventilation rates in accordance with ASHRAE 62.1-2010 or PBS P 100-2010 for filter efficiency, building type and zonal functions Use filtered Dedicated Outside Air Systems (DOAVS) Eliminate supply air plenums (i.e., UFAD) and minimize return air plenums to minimize cross-contamination per NRC 2007 Provide ADPI of at least 80% per P100-2010	Interface between BAS, fire/smoke, elevator safety, lighting, and security control systems in accordance with life-safety codes per PBS P100-2010 Control strategies for system shut-downs without exacerbating occupant exposure to externally or internally released CBR agents per ASHRAE 29-2009 Control strategies and oversight monitoring to manage indoor environmental quality (e.g., thermal, lighting, acoustics, and contaminant exposures), sustainability goals, and energy consumption in accordance with OPR	

Attribute	Enclosure Interactions: Thermal Transmission (Blast Resistance)	Enclosure Interactions: CBR Protection (External Releases)	HVAC System Interactions: Pressurization Control	HVAC System Interactions: Filtration Control	HVAC System Interactions: Sensing/Monitoring and Control	Cost Estimates
Benchmarks	Same as for FSL I: Minimized annual average sensible and latent enclosure loads (Qt ave) to comply with whole-building energy targets: 30% below ASHRAE 90.1-2004 (P+); 50% below ASHRAE 90.1-2004 (P++); or Other HP Goals per OPR.	Minimized peak loads (Qc) from additional types and intensities of externally released CBR contaminants, as determined by the threat analysis and based on enclosure tightness in accordance with draft ASTM Standard of 0.1 cfm/sf at 0.3 in. wg (75Pa) ΔPi-o with windows and doors closed	Enhanced pressurization sensing and control for interzonal differences: ΔPi-o and ΔPi-j for normal and extraordinary conditions in accordance with OPR Use Dedicated Outside Air Ventilation Systems (DOAVS), eliminate use air-side economizers, and increase use filtration to enhance pressurization control per PBS P100-2010, ASHRAE 29-2009, and NRC 2007 Eliminate supply air and return air plenums (i.e., use ductwork) to enhance pressurization control per NRC 2007 and ASHRAE 29-2009	Enhanced filtration control for gaseous contaminants (e.g., use adsorption filtration) Enhanced air distribution control and minimize time for removal (i.e., time constants) of externally or internally released particulate and gaseous contaminants by minimizing lengths of supply air and return air ductwork	Sensors and feedbackward or feedforeword control for preparation and response to threats of known CBR agents Enhanced control strategies for detection, identification and responses to external (and internal) releases of CBR agents Enhanced control strategies to optimize the goals of the eight HPB attributes (i.e., see WBDG): aesthetics, cost-effective, functional/operational, historic preservation, productive, safe and secure, and sustainable (i.e., including six parameters, one of which is energy use) during normal and extraordinary conditions	Incremental First Costs to FSL III: TBD ($/GSF) Incremental Operational and Maintenance Costs to FSL III: TBD ($/GSF/yr)
Comments: (Related Forcing Functions and Manipulated Variables)	High or Serious blast risk (ISC, ASHRAE 29-2009) Serious risk from natural, accidental or intentional events (ASHRAE 29-2009) Normal design weather/climate conditions At-risk site conditions (ISC, ASHRAE 29-2009) At-risk building type, size and function Increased blast resistant enclosure compared to FSL III Modified intrinsic thermal properties of enclosure Increased floor/wall area ratios from ISC FSL III (see Tables 2-4) Reduced percentage of glazing from ISC FSL III (see Tables 2-4)	High or Serious risk of external CBR release risk (ISC, ASHRAE 29-2009) Serious risk from natural, accidental or intentional events, including internal CBR releases (ASHRAE 29-2009) Normal design weather/climate conditions Increased threat of types, intensities and durations of outdoor contaminant releases compared to FSL III At-risk site conditions for natural, accidental, or intentional extraordinary events (ISC, ASHRAE 29-2009) Modified building type, size and function Modified intrinsic moisture and contaminant resistant properties of enclosure Modified design of operable windows and natural ventilation systems	Zone functions, configurations and isolation Type and size of HVAC System, including exhaust air system Location of Make-up-air intake(s) Location and types of seals for doors, windows, dampers, and interzonal penetrations Ductwork and plenum configuration Location of supply air diffusers and return air grilles (i.e., room air exchange effectiveness and response time)	Zone contaminant loads by type (i.e., particulate, gaseous, vapor) Type and size of HVAC System, including exhaust air system Type, efficiency and location of filtration devices Location of Make-up-air intake(s) Ductwork and plenum configuration Location of supply air diffusers and return air grilles (i.e., room contaminant removal effectiveness and response time)	Types of sensors and control loops in BAS Accuracy and response times of sensors and control loops Types of control strategies provided by BAS Types of interfaces between BAS and other supervisory systems (e.g., fire/life-safety, security)	
NRC 2007 Classification	LP-2				LP-4	

Table C.2-6: Response Functions for ISC 2009 Facility Security Level V (FSL-V).

- Corresponding ISC Level of Risk (LOR) and Level of Protection: **Very High**
- Corresponding ASHRAE 29-2009 Risk Category: **Critical**

Attribute	Enclosure Interactions: Thermal Transmission (Blast Resistance)	Enclosure Interactions: CBR Protection (External Releases)	HVAC System Interactions: Pressurization Control	HVAC System Interactions: Filtration Control	HVAC System Interactions: Sensing/Monitoring and Control	Cost Estimates
Metric	Thermal Loads (Btu/hr) through building enclosure and penetrations	Contaminant Loads (mass/hr)) through building enclosure and penetrations	Airflow Rate (cfm) or pressure (in. H2O) difference	Contaminant Removal Rate (mass/hr)	Safety/Security Energy Consumption (Btu/GSF/yr) Sustainability	First Costs ($/GSF) Operational and Maintenance Costs ($/ GSF/yr)
Value	$Q_t = U_o A_o \Delta T_{i\text{-}o}$	$Q_c = M_o A_o \Delta P_{i\text{-}o}$	$\Delta P_{s\text{-}r}$ or $\Delta V_{s\text{-}r}$	$E = V \sum \varepsilon_i c_i$		
Baseline	No special ISC requirements.	Provide emergency shut-down, SIP, and evacuation procedures Place air intakes on rooftop or on wall at least 30 feet or 3 stories above grade Ensure that the enclosure of the isolated loading docks and mail room are full-height construction and are sealed to the floor, roof or ceiling above No other special ISC requirements	Provide separate isolated HVAC systems in lobbies, loading docks, mail rooms, and other locations susceptible to CBR attack that are isolated from other building areas No other special ISC requirements.	Use HEPA filters or functional equivalents (i.e., MERV 17 – 20) on AHUs serving critical areas, mailrooms and lobbies, including outside ones (AHUs) and in the supply air stream of recirculating AHUs Provide gas adsorption filters on recirculated air as well as on outside air intakes which serve critical areas No other special ISC requirements	Provide Intrusion Detection System (IDS) coverage and access control of ventilation equipment and control rooms Provide two or more redundant locations for one-step shut-off and exhaust system for air handlers Control movement of elevators and close applicable doors and dampers to seal building Provide an emergency response module to the building's energy management system (i.e., BAS) to switch the system to a prescribed emergency response mode Provide instrumentation to monitor pressure relationship established by the isolated systems Install CBR detection technology to protect critical areas against known credible threats No other special ISC requirements	Incremental First Costs to FSL IV: $20 - 100/GSF depending on sensing and control strategies, building type, zonal functions, climate zones and other factors Incremental Operational and Maintenance Costs to FSL IV: $2 - 10 / GSF/yr depending on building type, zonal functions, climate zones and other factors

Attribute	Enclosure Interactions		HVAC System Interactions			Cost Estimates
	Thermal Transmission (Blast Resistance)	CBR Protection (External Releases)	Pressurization Control	Filtration Control	Sensing/Monitoring and Control	
Baseline (cont.)	Maintain overall heat transfer coefficient (Uo) at FSL I values by modifying enclosure to compensate for added structural support (e.g., thermal bridges) Achieve same Qt and energy target as for FSL I during normal conditions	Maintain overall moisture and contaminant transfer coefficients (Mo) at FSL I values by modifying the enclosure to compensate for additional types and intensities of external CBR releases as determined by the threat analysis Use tight shut-off dampers for Make-up Air Intakes and Exhaust Air Discharges Outside air intakes to be located on roof or high wall (i.e., high rise building) - > 30 ft above grade per ASHRAE 29-2009 Achieve same Qc as for FSL I during normal and extraordinary conditions based on compliance with PBS P100-2010 enclosure tightness criteria of 0.1 cfm/sf at 0.3 in. wg (75 Pa) with windows and doors closed	Increase number of perimeter and interior zones in accordance with ASHRAE 29-2009 and OPR Provide separate air distribution system for each pressurization zone, including public areas, per ASHRAE 29-2009 Provide AHUs on each floor (i.e., floor-by-floor) per ASHRAE 29-2009 Ductwork to be routed to avoid unauthorized access per ASHRAE 29-2009 Provide ΔPs-r or ΔVs-r = 10%, accounting for interzonal pressurization requirements per ASHRAE 29-2009; exhaust systems and building tightness, per PBS P 100-2010; and outside air for ventilation in accordance with ASHRAE 62.1-2010 for building type and zonal functions	> MERV 17 for all AHUs and > MERV 10 for terminal units (e.g., FCUs) per PBS P100-2010 and ASHRAE 29-2009 > MERV 17 for recirculation AHUs in each pressurization zone per ASHRAE 29-2009 In areas specified by OPR, provide local air washers with laminar airflow and local (high efficiency) filtration of recirculation air per NRC 2007 Ventilation rates in accordance with ASHRAE 62.1-2010 or PBS P 100-2010 for filter efficiency, building type and zonal functions Use filtered Dedicated Outside Air Systems (DOAVS) Eliminate supply air plenums (i.e., UFAD) and minimize return air plenums to minimize cross-contamination per NRC 2007 Provide ADPI of at least 80% per P100-2010	Interface between BAS, fire/smoke, elevator safety, lighting, and security control systems in accordance with life-safety codes per PBS P100-2010 Control strategies for system shut-downs without exacerbating occupant exposure to externally or internally released CBR agents per ASHRAE 29-2009 Control strategies and oversight monitoring to manage indoor environmental quality (e.g., thermal, lighting, acoustics, and contaminant exposures), sustainability goals, and energy consumption in accordance with OPR	
Benchmarks	Same as for FSL I: Minimized annual average sensible and latent enclosure loads to comply with whole-building energy targets: 30% below ASHRAE 90.1-2004 (P+); 50% below ASHRAE 90.1-2004 (P++); or Other HP Goals per OPR.	Minimized peak loads (Qc) from additional types and intensities of externally released CBR contaminants, as determined by the threat analysis and based on enclosure tightness in accordance with draft ASTM Standard of 0.1 cfm/sf at 0.3 in. wg (75Pa) ΔPi-o with windows and doors closed	Enhanced pressurization sensing and control for interzonal differences: ΔPi-o and ΔPi-j for normal and extraordinary conditions in accordance with OPR Use Dedicated Outside Air Ventilation Systems (DOAVS), eliminate use air-side economizers, and increase use filtration to enhance pressurization control per PBS P100-2010, ASHRAE 29-2009, and NRC 2007 Eliminate supply air and return air plenums (i.e., use ductwork) to enhance pressurization control per NRC 2007 and ASHRAE 29-2009	Enhanced filtration control for gaseous contaminants (e.g., use adsorption filtration) Enhanced air distribution control and minimize time for removal (i.e., time constants) of externally or internally released particulate and gaseous contaminants by minimizing lengths of supply air and return air ductwork	Sensors and feedbackward or feedforeword control for preparation and response to threats of known CBR agents Enhanced control strategies for detection, identification and responses to external (and internal) releases of CBR agents Enhanced control strategies to optimize the goals of the eight HPB attributes (i.e., see WBDG): aesthetics, cost-effective, functional/operational, historic preservation, productive, safe and secure, and sustainable (i.e., including six parameters, one of which is energy use) during normal and extraordinary conditions	Incremental First Costs to FSL IV: TBD ($/GSF) Incremental Operational and Maintenance Costs to FSL IV: TBD ($/GSF/yr)

Attribute	Enclosure Interactions: Thermal Transmission (Blast Resistance)	Enclosure Interactions: CBR Protection (External Releases)	HVAC System Interactions: Pressurization Control	HVAC System Interactions: Filtration Control	HVAC System Interactions: Sensing/Monitoring and Control	Cost Estimates
Comments: **(Related Forcing Functions and Manipulated Variables)**	Very High or Critical blast risk (ISC, ASHRAE 29-2009) Critical risk from natural, accidental or intentional events (ASHRAE 29-2009) Normal design weather/climate conditions At-risk site conditions (ISC, ASHRAE 29-2009) At-risk building type, size and function Increased blast resistant enclosure compared to FSL IV Modified intrinsic thermal properties of enclosure Increased floor/wall area ratios from ISC FSL IV (see Tables 2- 5) Reduced percentage of glazing from ISC FSL IV (see Tables 2-5)	Very High or Critical risk of external CBR release risk (ISC, ASHRAE 29-2009) Critical risk from natural, accidental or intentional events, including internal CBR releases (ASHRAE 29-2009) Normal design weather/climate conditions Increased threat of types, intensities and durations of outdoor contaminant releases compared to FSL IV At-risk site conditions for natural, accidental, or intentional extraordinary events (ISC, ASHRAE 29-2009) Modified building type, size and function Modified intrinsic moisture and contaminant resistant properties of enclosure Modified design of operable windows and natural ventilation systems	Zone functions, configurations and isolation Type and size of HVAC System, including exhaust air system Location of Make-up-air intake(s) Location and types of seals for doors, windows, dampers, and interzonal penetrations Ductwork and plenum configuration Location of supply air diffusers and return air grilles (i.e., room air exchange effectiveness and response time)	Zone contaminant loads by type (i.e., particulate, gaseous, vapor) Type and size of HVAC System, including exhaust air system Type, efficiency and location of filtration devices Location of Make-up-air intake(s) Ductwork and plenum configuration Location of supply air diffusers and return air grilles (i.e., room contaminant removal effectiveness and response time)	Types of sensors and control loops in BAS Accuracy and response times of sensors and control loops Types of control strategies provided by BAS Types of interfaces between BAS and other supervisory systems (e.g., fire/life-safety, security)	
NRC 2007 Classification	LP-2				LP-4	

Appendix C.3 Calculations for CO_2e, PV Production, and Percentage of Whole-Building Energy Target Attributable to the Building Enclosure

Table C.3-1: Calculations for CO_2e, PV Power, and Percent Energy Distribution – CO_2E

Climatic Zone	Description	e-Grid Region (from EPA eGRID2007 Version 1.1)	Target EUI for HVAC System Type for Offices, kBtu/GSF-yr			El/Fuel Mix Ratio for HVAC System Type (Assumed)			CO_2e Conversion Factor		"CO_2e, lb/GSF-yr (Calculated)[29]		
			Non-customized (Baseline - 90.1-2004, from PNNL baseline values - PNNL reports 19341 and 19004)	Semi-customized (P+ = 30% below 90.1-2004 target value, in compliance with P100-2010, Section 1.9)	Customized (P++ = 50% below 90.1-2004 target value, from PNNL baseline values - PNNL reports 19341 and 19004)	Non-customized (Baseline)	Semi-customized (HP)	Customized (HP+)	Electricity, lb CO_2e/kBtu (from EPA eGRID2007 Version 1.1)*	Natural Gas, lb CO_2e/kBtu (from www.epa.gov/cleanenergy/energy-resources/refs.html, accessed 2/27/11)**	Non-customized (Baseline)	Semi-customized (P+)	Customized (P++)
4A	Washington DC	SRVC	60	42	30	0.7	0.8	0.9	0.33	0.11	16	11	8
6A	Minneapolis MN	MROW	70	43	31	0.6	0.7	0.8	0.53	0.11	25	15	11
5B	Denver CO	RMPA	55	33	26	0.6	0.7	0.8	0.55	0.11	21	12	9
3C	San Francisco CA	CAMX	46	31	22	0.8	0.9	1	0.21	0.11	9	6	4
2B	Phoenix AZ	AZNM	54	38	25	0.8	0.9	1	0.38	0.11	18	12	8
1A	Miami FL	FRCC	51	39	26	0.9	1	1	0.39	0.11	18	14	9

Conversion Factors:

* Lb CO_2e/MWh from e-Grid x MWh/1000 kWh x kWh/3414 Btu x 1000 Btu/kBtu = lb CO_2e/kBtu

** 0.005 metric tons CO_2e/therm of natural gas x 1000 kg/metric ton x 2.2 lb/kg x therm/100,000 Btu x 1000 Btu/kBtu = 0.11 lb CO_2e/kBtu

Table C.3-2: Calculations for CO_2e, PV Power, and Percent Energy Distribution – PV Power Production

Climatic Zone	Description	e-Grid Region (from EPA eGRID2007 Version 1.1)	Target EUI for HVAC System Type for Offices, kBtu/GSF-yr: Non-customized (Baseline - 90.1-2004, from PNNL baseline values - PNNL reports 19341 and 19004)	Target EUI for HVAC System Type for Offices, kBtu/GSF-yr: Semi-customized (P+ = 30% below 90.1-2004 target value, in compliance with P100-2010, Section 1.9)	Target EUI for HVAC System Type for Offices, kBtu/GSF-yr: Customized (P++ = 50% below 90.1-2004 target value, from PNNL baseline values - PNNL reports 19341 and 19004)	Estimated PV solar radiation availability, kwh/m²-day (Based on PV Solar Radiation Map - NREL, May 2004): Min.	Estimated PV solar radiation availability: Max.	Assumed PV Efficiency	Estimated PV energy production, kWh/day-m² of plate: Min.	Estimated PV energy production: Max.	Estimated PV annual energy production, kWh/SF-Plate[1]: Min.	Estimated PV annual energy production: Max.	Estimated Lighting and Plug Load Energy (kWh/GSF-yr)[2]: Baseline	Estimated Lighting and Plug Load Energy: P+	Estimated Lighting and Plug Load Energy: P++	Estimated Lighting and Plug Load Energy: F/HP[4]	Plate area (SF) to residual EUI (max): Baseline	Plate area (SF) to residual EUI (max): P+	Plate area (SF) to residual EUI (max): P++	Plate area (SF) to residual EUI (max): F/HP	Plate area (SF) to residual EUI (min): Baseline	Plate area (SF) to residual EUI (min): P+	Plate area (SF) to residual EUI (min): P++	Plate area (SF) to residual EUI (min): F/HP	Estimated CapEx for Lighting and Plug Load (\$/GSF)[3]: Baseline	Estimated CapEx for Lighting and Plug Load: P+	Estimated CapEx for Lighting and Plug Load: P++	Estimated CapEx for Lighting and Plug Load: F/HP[5]
4A	Washington DC	SRVC	60	42	30	4.5	5	0.15	0.7	0.8	15.7	17.4	8.8	6.0	4.6	4.1	0.6	0.3	0.5	0.7	0.1	0.1	0.9	2.0	48	33	25	43
6A	Minneapolis MN	MROW	70	43	31	4.5	5	0.15	0.7	0.8	15.7	17.4	8.8	6.0	4.6	4.1	0.6	0.4	0.3	0.5	0.5	0.3	0.3	0.5	48	33	25	45
5B	Denver CO	RMPA	55	33	26	6	6.5	0.15	0.9	1.0	20.9	22.7	8.8	6.0	4.6	4.1	0.4	0.3	0.2	0.3	0.4	0.3	0.2	0.3	48	33	25	38
3C	San Francisco CA	CAMX	46	31	22	5.5	6	0.15	0.8	0.9	19.2	20.9	8.8	6.0	4.6	4.1	0.5	0.3	0.2	0.3	0.4	0.3	0.2	0.3	48	33	25	32
2B	Phoenix AZ	AZNM	54	38	25	6.5	7	0.15	1.0	1.1	22.7	24.4	8.8	6.0	4.6	4.1	0.4	0.3	0.2	0.3	0.4	0.2	0.2	0.3	48	33	25	36
1A	Miami FL	FRCC	51	39	26	5	5.5	0.15	0.8	0.8	17.4	19.2	8.8	6.0	4.6	4.1	0.5	0.3	0.3	0.4	0.5	0.3	0.2	0.4	48	33	25	38

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC

Notes:

1. From Column G, this table, x 5 day/wk x 50 wks/yr x $m^2/10.76\ ft^2$.
2. From Columns G-O in El and Thermal Energy Dist Table = kWh/GSF-yr.
3. From Columns N-P and Q-S. Ex: (8.8 kWh/GSF-yr x \$11,000/kW) / (2,000hrs/yr).
4. Based on estimate that lighting and plug load is 90% of P++.
5. Based on estimate that residual EUI for ZNE is 90% of P++.

Table C.3-3: Calculations for CO_2e, PV Power, and Percent Energy Distribution – Electrical Use and Thermal Energy Distribution

Climatic Zone	Description	e-Grid Region (from EPA eGRID2007 Version 1.1)	Target EUI for HVAC System Type for Offices, kBtu/GSF-yr			Annual Electrical Use for Internal Lighting (kWh/GSF)			Annual Electrical Use for External Lighting (kWh/GSF)			Annual Electrical Use for Plug and Fixed* Loads (kWh/GSF)			Annual Energy Consumption for Service Water Heating (kBtu/GSF)			Residual Annual Energy Consumption for Heat Transfer of Lighting, Plug and Fixed, SWH, Occupant, Ventilation, Enclosure Loads through HVAC system (kBtu/GSF)		
			Non-customized (Baseline - 90.1-2004, from PNNL baseline values - PNNL reports 19341 and 19004)	Semi-customized (P+ = 30% below 90.1-2004 target value, in compliance with P100-2010, Section 1.9)	Customized (P++ = 50% below 90.1-2004 target value, from PNNL baseline values - PNNL reports 19341 and 19004)	Baseline - from PNNL reports 19341 and 19004	P+, interpolated from columns G and I	"P++, from PNNL reports 19341 and 19004"	Baseline - from PNNL reports 19341 and 19004	"P+, interpolated from columns J and L"	"P++, from PNNL reports 19341 and 19004"	Baseline - from PNNL reports 19341 and 19004	"P+, interpolated from columns M and O"	"P++, from PNNL reports 19341 and 19004"	Baseline -from PNNL reports 19341 and 19004	"P+, interpolated from columns P and R"	"P++, from PNNL reports 19341 and 19004) "	"Baseline (EUI - Lighting, Plug and SWH values kBtu/GSF)"	"P+, (EUI - Lighting, Plug and SWH values kBtu/GSF)"	"P++, (EUI - Lighting, Plug and SWH values kBtu/GSF)"
4A	Washington DC	SRVC	60	42	30	3.3	2.3	1.6	1.7	0.9	0.5	3.8	2.8	2.4	1.1	1.0	1.0	29.1	20.7	13.6
6A	Minneapolis MN	MROW	70	43	31	3.3	2.3	1.6	1.7	0.9	0.5	3.8	2.8	2.4	1.2	1.1	1.1	39.0	21.6	14.5
5B	Denver CO	RMPA	55	33	26	3.3	2.3	1.6	1.7	0.9	0.5	3.8	2.8	2.4	1.2	1.0	1.0	24.0	11.7	9.5
3C	San Francisco CA	CAMX	46	31	22	3.3	2.3	1.6	1.7	0.9	0.5	3.8	2.8	2.4	1.1	1.0	0.9	15.1	9.7	5.6
2B	Phoenix AZ	AZNM	54	38	25	3.3	2.3	1.6	1.7	0.9	0.5	3.8	2.8	2.4	0.8	0.7	0.7	23.4	17.0	8.8
1A	Miami FL	FRCC	51	39	26	3.3	2.3	1.6	1.7	0.9	0.5	3.8	2.8	2.4	0.7	0.7	0.7	20.5	18.0	9.9
A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U

Note:

Data for "fixed electrical loads" not available in PNNL Reports.

Table C.3-4: Calculations for CO_2e, PV Power, and Percent Energy Distribution – Thermal Energy Distribution

			Target EUI for HVAC System Type for Offices, kBtu/GSF-yr			Residual Annual Energy Consumption for Heat Transfer of Lighting, Plug and Fixed, SWH, Occupant, Ventilation, Enclosure Loads through HVAC system (kBtu/GSF)			Annual Energy Consumption for heat dissipation of Internal Lighting, Plug and Fixed Loads (kBtu/GSF)[1]			Annual Energy Consumption for heat dissipation of Occupant Loads (kBtu/GSF)[2]			Annual Energy Consumption available for heat dissipation of Enclosure and Ventilation/ Pressurization Loads (kBtu/GSF)[3]			Estimated Annual Energy Consumption for Ventilation/ Pressurization Loads (kBtu/GSF)[4, 5]			Annual Energy Consumption available for heat dissipation of Enclosure Loads (kBtu/GSF)[6]			Percent of Target EUI available for heat dissipation of Enclosure Loads			CO_2e, lb/GSF-yr (Calculated) attributable to heat dissipation of Enclosure Loads		
Climatic Zone	Description	e-Grid Region (from EPA eGRID2007 Version 1.1)	Non-customized (Baseline - 90.1-2004, from PNNL baseline values - PNNL reports 19341 and 19004)	Semi-customized (P+ = 30% below 90.1-2004 target value, in compliance with P100-2010, Section 1.9)	Customized (P++ = 50% below 90.1-2004 target value, from PNNL baseline values - PNNL reports 19341 and 19004)	Baseline (EUI - Lighting, Plug and SWH values)	P+, (EUI - Lighting, Plug and SWH values)	P++, (EUI - Lighting, Plug and SWH values)	Baseline	P+	P++	Baseline	P+	P++	Baseline	P+	P++	Baseline	P+	P++	Baseline	P+	P++	Baseline	P+	P++	Baseline	P+	P++
4A	Washington DC	SRVC	60	42	30	29.1	20.7	13.6	6.8	3.5	2.0	1.3	0.9	0.6	21.0	16.3	11.0	12.8	10.0	1.9	8.2	6.4	9.1	14	15	30	2	2	2
6A	Minneapolis MN	MROW	70	43	31	39.0	21.6	14.5	6.8	3.5	2.8	1.3	0.9	0.6	30.9	17.2	11.1	15.0	9.8	2.3	15.9	7.4	8.8	23	17	28	6	3	3
5B	Denver CO	RMPA	55	33	26	24.0	11.7	9.5	6.8	3.5	2.8	1.3	0.9	0.6	15.9	7.3	6.1	11.4	5.4	1.7	4.5	1.9	4.4	8	6	17	2	1	2
3C	San Francisco CA	CAMX	46	31	22	15.1	9.7	5.6	6.8	3.5	2.8	1.3	0.9	0.6	7.0	5.3	2.2	5.3	5.0	1.0	1.7	0.3	1.2	4	1	6	0	0	0
2B	Phoenix AZ	AZNM	54	38	25	23.4	17.0	8.8	6.8	3.5	2.8	1.3	0.9	0.6	15.3	12.6	5.4	8.0	7.7	1.3	7.3	4.9	4.1	14	13	16	2	2	1
1A	Miami FL	FRCC	51	39	26	20.5	18.0	9.9	6.8	3.5	2.8	1.3	0.9	0.6	12.4	13.6	6.5	4.1	4.3	1.7	8.3	9.4	4.8	16	24	18	3	3	2
A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD

Notes:

1. Energy for heat dissipation from lighting and plug loads (see Page 3, columns G - O. Coeffient of performance for transferring elctrical load assumed as 3.5 for baseline, 5.0 for P+ and 7.0 for P++.
2. Assumed energy for Occupant loads: P/200 GSF * 450 Btu/hr-person * 2000 hrs/yr * kBtu/1000 Btu = 4.5 kBtu/GSF-yr.
3. Annual energy available for enclosure and ventilation loads (kBtu/GSF).
4. The distribution of energy is not rational. The big issue is that the PNNL reports do not account for the energy to provide the lighting and plug loads, in addition to the energy needed to dissipate the heat from these sources. We have accounted for both the energy required to provide the electrical and service water heating, and for the energy required to dissipate the building heat gained from the internal lighting and plug loads (fixed electrical loads have not been considered in these calculations).
5. We have estimated the annual energy consumption for ventilation and pressurization based on five assumptions:
   1) the outdoor air flow rate for ventilation and pressurization has been assumed constant at 0.1 cfm/GSF for Baseline, P+ and P++.
   2) The annual cooling energy for 4A (WDC) is estimated as: 1.18 ton-hrs/cfm x 12 kBtu/ton x 0.1 cfm/GSF = 1.42 kBtu/GSF.
   3) The annual heating energy for 4A is estimated as: 1.14 therm-hrs/cfm x 100 kBtu/therm x 0.1 cfm/GSF = 11.4 kBtu/GSF.
   4) the annual energy consumption for heating and cooling in 4A is 1.42+11.4 = 12.8 kBtu/GSF.
   5) Adjustment factors have been applied for climate, availability of air-side economizer (P+) and for availablility of enthalpy heat recovery device (P++).
6. The annual energy consumption values for dissipation of heating and cooling loads from the enclosure are assumed to be the residual values from columns P-R less columns S-U for baseline, P+ and P++.

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